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TEXT-BOOK

18

OF

PHYSIOLOGY,

GENERAL, SPECIAL, AND PRACTICAL.

BY

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PART I.

GENERAL PHYSIOLOGY.

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INTRODUCTION.

Physiology is that science which treats of the phenomena observed in living beings. Of these, such as occur in plants are now taught by the Professor of Botany, and such as distinguish the lower animals are comprehended in the lectures of the Professor of Zoology. By Physiology, therefore, at present, is generally understood a knowledge of the functions of the human body—in other words, human physiology ; whatever facts, however, throw light upon this last branch of the subject, observed in any of the kingdoms of nature, are made available for the purpose. The student, after obtaining a certain knowledge of Anatomy—which teaches us the structure and relations of the parts of the body, as determined by dissection—should, in the first instance, study the chemical, histological, and physico-vital phenomena presented by the tissues of which the organism is composed. This has taught us that all function is dependent upon the alterations and actions upon one another of the ultimate molecules—chemical and histological—of which these tissues are made up, and that the sum of the forces they evolve, constitutes vitality. He should next pay attention to the special physiology of organs, which, according to the functions they subserve, are arranged into the three groups of Nutrition, Innervation, and Reproduction. Lastly, he should exercise himself in the methods and in the use of the instruments which have become so necessary for clearly comprehending and making additions to the truths of physiological science. This branch of the subject I have for many years taught in the Laboratory of this University under the name of Practical Physiology.

PART I.

GENERAL PHYSIOLOGY.

General Physiology comprehends, 1st, the Chemistry; 2d, the Histology; and, 3d, the Physical and Vital properties of the Tissues,—with the consideration of what is understood by life or vitality.

CHEMISTRY OF THE TISSUES.

At one time it was supposed that the peculiar character of the chemical compounds formed in living bodies was due to the action of a mysterious force, termed vital force, but later researches have shewn that many of those compounds may be produced in the laboratory, either by the direct combination of their elements, or by chemical changes produced in inorganic compounds. For example, cyanogen gas (C_2N) is a compound of carbon and nitrogen, and may be formed by the direct union of its elements. This, combined with ammonium, forms cyanate of ammonium, and by a molecular transformation of the elements of the latter, urea, a well known organic substance excreted by the kidneys, is formed. Thus :—

$$\underset{\text{Ammon. Cyanate.}}{CNNH_4O} = \underset{\text{Urea.}}{COH_4N_2}$$

In like manner, a large number of organic compounds, known as alcohols, aldehydes, acids, ethers, amines, &c., may be prepared from hydrocarbons, such as marsh gas and ethylene. But although many of the proximate principles of animals may be prepared artificially by ordinary chemical actions without the agency of a vital force, we cannot for a moment suppose that chemistry alone will ever succeed in producing even the simplest plant or animal.

Chemical Elements.

As there have lately been changes in the chemical doctrines concerning atoms, and their symbols, relative weights, and powers, it is necessary before we enter upon a detailed examination of the chemistry of the body, to explain certain terms often employed.

1. By an "element" is meant matter which by no known chemical means can be resolved into two or more heterogeneous substances. For example, it is at present impossible to split oxygen or hydrogen into any other substances—hence they are called elements.

2. An "atom" is the smallest amount of a chemical element which can exist in a compound. An atom is never found in a free state. An atom of hydrogen is represented by the symbol H.

3. A chemical "molecule" is a combination of two or more atoms, and the atoms may be atoms of the same or of different substances. A molecule can exist by itself. A simple molecule, made up of two atoms of the same element, is seen in the case of a molecule of hydrogen = HH. A molecule of hydrochloric acid is made up of a combination of an atom of hydrogen with an atom of chlorine = HCl.

The limits up to which the number of atoms in a molecule may increase are at present unknown. According to Dr Thudicum,* a molecule of hæmatocrystallin, the principal ingredient of the blood corpuscles, is represented by the formula $C_{600}H_{960}N_{154}FeS_3O_{177}$, representing 1895 atoms. It is remarkable that by the law of condensation, if these 1895 atoms could be brought into the gaseous state, they would occupy two volumes, the same space as would be filled by a molecule of watery vapour containing three atoms.

The elementary chemical substances at present known in nature are sixty-five in number. Of these thirteen are non-metallic, and fifty-two are metallic. Only twenty out of this number enter into the composition of organized beings, namely, *Non-metallic Elements*—Oxygen, hydrogen, carbon, nitrogen,

13 = 65
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[*] Tenth Report of Medical Officer of Privy Council, 1867. Appendix, No. 7, Dr Thudicum's Report.

phosphorus, sulphur, chlorine, fluorine, iodine, bromine, and silicon; *Metallic Elements*—Potassium, sodium, calcium, magnesium, aluminium, iron, manganese, copper, and lead.

Of these twenty elements, the most essential are oxygen, hydrogen, carbon, and nitrogen, which may be regarded as the basis of all organic matter.

Oxygen, the most abundant of all the elements, is an essential constituent of all living organisms, independently of its existence in the water of the tissues.

Hydrogen also exists in the water of the tissues, of which it forms one-ninth by weight, and it is found in almost all organic matters.

Carbon is the characteristic element of organic bodies; so much so, that when any substance exposed to heat on a piece of platinum foil becomes blackened or charred, from the separation of carbon, it is known to be of organic origin. Carbon is associated with oxygen and hydrogen to form many of the simpler organic compounds.

Nitrogen. In more highly organised substances such as albumin, fibrin, and casein, nitrogen is superadded. Free nitrogen is said to be found in the air bladders of fish, and in other cavities of the animal body.

Phosphorus is found in the urine (where it was first discovered), in blood, and in the proximate principles, albumin and fibrin, which enter so largely into the composition of all the soft tissues. It also exists largely in nervous tissue, and in bone, where, in combination with lime, it forms tribasic phosphate of calcium, the chief mineral constituent of that important structure.

Sulphur is necessary to the constitution of albumin, fibrin, and casein, and it exists in the taurin of bile, and the cystin of urine. It also forms sulphates in combination with oxygen and various bases.

Chlorine exists chiefly in combination with sodium and potassium, forming chlorides of sodium and potassium—the former being a most important constituent of all animals.

Fluorine has been found in very small quantity in the ash of blood, milk, and bone.

Iodine and *Bromine* have been found in the secretions of persons taking cod liver oil, or in the habit of eating marine plants and animals, all of which contain these substances.

Silicon, in form of silicic acid, is seldom absent from the ash of organic matters, though it exists in very small quantity. According to Gorup Besanez, it forms a constituent of feathers and of hair.

Potassium-salts enter largely into the composition of the body, forming essential constituents of many organs and fluids, as for instance, flesh and milk. They are derived chiefly from the vegetable kingdom.

Sodium in combination with chlorine, sulphuric, phosphoric, carbonic, and various organic acids, exists in every tissue of the body.

Calcium exists in the bones of animals, as carbonate and phosphate, and it also combines with organic acids.

Magnesium in the form of carbonate and phosphate, is found in flesh, blood, milk, urine, &c.

Iron is one of the most important elements of the body, as it forms about seven per cent. of hæmatin, the red colouring matter of the blood corpuscles.

Aluminium, *Manganese*, *Copper*, and *Lead*, are only occasionally found in the tissues, and their presence may be accounted for by some peculiarities in the chemical nature of the food used. It has also been suggested that the copper and lead, rarely met with, may have been derived from the apparatus made use of in the chemical research.

COMPOUND RADICLES.—Numerous hypotheses have been advanced to explain how the twenty elementary substances above mentioned combine to form the tissues of a living being.

Before the days of Dumas and Liebig, the opinion generally held was, that the elements oxygen, hydrogen, nitrogen, and carbon, combined to form ternary and quaternary compounds, which made up the tissues and fluids of the body.

M. Raspail taught that oxygen and hydrogen first united to form water, which, entering into combination with carbon, formed a ternary compound. In the same manner, nitrogen entered into the composition of the tissues, through the agency of an ammoniacal salt, and the union of this salt with water formed nitrogenised organic matter.

The next theory was that of Liebig, which has been termed the theory of compound radicles. Among the numerous substances derived from the organs of an animal, groups are found, the members of which exhibit a close analogy with each other, both in chemical constitution and in the decompositions they undergo. For example, each member of the following series of alcohols, contains an atom of carbon, and two atoms of hydrogen, less than the one immediately above it.

Wood spirit,	CH_4O.
Ethylic alcohol,	C_2H_6O.
Propylic alcohol,	C_3H_8O.
Butylic alcohol,	$C_4H_{10}O$.

Each of these compounds is evidently analogous to wood spirit, but contains an additional number of multiples of the hydrocarbon CH_2, and the group forms what chemists term a homologous series. By various chemical processes, each alcohol yields an ether, an aldehyde, an acid, &c., and these derived compounds form a heterologous series. Liebig explains this similarity existing between members of such a homologous series, by the hypothesis that in each of them there is a certain group of elements, which he terms the radicle of the series—the radicle of the above series being methyl (CH_3). Thus wood spirit is the hydrated oxide of methyl (CH_3HO). The ether derived from wood spirit, is the oxide of the radicle $(CH_3)_2O$. A radicle may be simple or compound. The radicles of inorganic chemistry are usually simple; those of organic chemistry are complex; but in either case, the radicle plays the part of a base and discharges a function analogous to that of potassium and its salts.

In carrying these general views into detail, M. Dumas made the beautiful generalisation, that an animal should be regarded, in a chemical point of view, as an apparatus of combustion, which incessantly returns to the atmosphere carbonaceous matters in the shape of carbonic acid (CO_2), hydrogen as a constituent of water (H_2O), and free nitrogen in the form of ammonium oxide (NH_4O). In short, from the animal kingdom as a whole, there is constantly given off carbonic acid, watery vapour, and nitrogen. Vegetables, on the other hand, absorb and fix these substances, retaining the carbon and hydrogen, and setting free the oxygen. They also abstract nitrogen directly from the air, or indirectly from ammonium oxide, or nitric acid. Vegetables, for the most part, form organic matter under the influence of solar light. They pass ready formed, as food into the bodies of animals, which, during their life, or after their death, restore them to the atmosphere from which they were originally derived. Thus the animal kingdom is an apparatus of combustion, the vegetable kingdom an apparatus of reduction ; the one produces the elements which the other consumes ; so that, in the language of Dumas, they are the " offspring of the air." They come from the atmosphere, and return to it again.

The various mineral matters which enter into the constitution of living beings, exhibit the same dependence which animals have upon vegetables, and these, again, upon inorganic matter. They simply pass through living beings, as it were, to serve certain important purposes in the scheme of life. Let us take lime and sulphur as examples. Rain water, loaded with the carbonic acid of the air, falls upon calcareous hills, and carbonate of lime, in a state of solution, enters rivers, and is by them carried to the ocean, where it is seized upon by millions of animals, and converted into their external skeletons or shells. The water of rivers and springs also is absorbed by plants, and drank by animals ; and so lime enters into their substance, and is converted into various salts of that base, such as oxalates, tartrates, phosphates, &c. Phosphate of lime is the principal element of the bones, besides entering more or less into the constitution of the other tissues of the superior animals, which are continually excreting, as well as assimilating it. Lastly, on their death, the lime is dispersed in various ways ; even the bones crumble to pieces ; and so the mineral returns to the soil, from whence it came. Sulphur passes from one region to another, in a similar manner, from the sea, which contains sulphur in large quantities, to the atmosphere, thence to the soil, and thence to plants and animals, from whence again it returns to the bosom of the ocean.

These incessant exchanges between the soil or atmosphere, plants, and animals, constitute the theory known as " the chemical balance of organic nature."

PROXIMATE PRINCIPLES.

The various elements above enumerated arrange themselves under the influence of chemico-vital laws, to form what are termed " Proximate principles." A proximate principle, strictly speaking, is any substance, whether simple or compound, which exists under its own form in the animal solid or fluid, and which can be extracted by means which do not alter or destroy its chemical properties. For example, tricalcic phosphate is a proximate principle of bone; but phosphoric acid is not so, since it does not exist as such in bony tissue, but is produced only after the decomposition of the tricalcic phosphate; still less phosphorus, which is obtained only by decomposing the phosphoric acid by the action of charcoal.

The chemical proximate principles, which are of such paramount importance, in constituting the substance of the body, may be divided into four groups—namely, 1st. the albuminous; 2d. the fatty; 3d. the mineral; and, 4th. the pigmentary principles. All these are more or less associated together in every texture and fluid, but some abound in one, and others in another, giving to each peculiar characters.

1. The Albuminous Principles.

The albuminous principles are divided into, 1st. Albuminates; 2d. Albuminoids; and, 3d. Albuminous derivatives.

Albuminates.—Mulder supposes that all the albuminates contain the same radicle $C_{18}H_{27}N_4O_6$, which he terms *protein*, combined with small quantities of sulphur and phosphorus.

1. *Albumin.*—Composition in 100 parts—C53·3,H7·1,N15·7, O22·1,S1·8 (Lieberkuhn). Various chemists have found a very small proportion of phosphorus in albumin. According to Mulder, albumin is a compound of protein and a hypothetical substance termed sulphamide—

$$\underset{\text{Protein.}}{5C_{18}H_{27}N_4O_6} + \underset{\text{Sulphamide.}}{N_2H_4S} = \underset{\text{Albumin.}}{C_{90}H_{139}N_{22}SO_{30}}.$$

Albumin forms the white of eggs, where it exists as albuminate of sodium, and it occurs in large quantity in all the animal fluids which contribute to nutrition. It is also found in most of the animal solids. It does not occur in the body in a free state, but is always associated with an alkaline base forming an alkaline albuminate. It exists in two forms—soluble and insoluble albumin—the former being easily converted into the latter by the agency of heat, as in the familiar example of boiling an egg; but it is doubtful if albumin is ever present in the living body in its insoluble state.

Nearly all acids precipitate it from its solutions. Nitric acid does this so readily, that it is used as a test of the presence of soluble albumin. When boiled with hydrochloric acid, ammonium chloride, leucin, tyrosin, and other substances are formed. It is insoluble in alcohol and ether. It is precipitated by corrosive sublimate and potassium ferrocyanide. When distilled with manganese protoxide, and sulphuric acid, it is decomposed into acetic, propionic, butyric, and benzoic aldehydes, with the corresponding acids. Two modifications of albumin, derived from pathological fluids, have been described, —paralbumin and metalbumin,—the former being not completely precipitated by heat, and the latter not being thrown down by potassium ferrocyanide.

This substance is of the greatest physiological importance. The egg of a bird contains hardly any other nitrogenous compound except albumin, the yolk containing, in addition, a yellow fat, with traces of iron and other organic matters. Yet we see in the process of incubation, during which no foreign matter except atmospheric air can be introduced, or can take any part in the development of the animal, that feathers, claws, blood corpuscles, cellular tissue, and vessels are produced.

2. *Fibrin.*— Composition in 100 parts—C52·7,H6·9,N15·4, O23·5,S1·2 (Mulder). Albumin may be converted into fibrin by oxidation, as may be shewn by passing a stream of oxygen through defibrinated serum, when the albumin in the latter is converted into fibrin, and separates in thirty-six hours in small clots. It is completely insoluble in cold water, in alcohol, and in ether. Fibrin is present in the body in a fluid state. It is found in small quantity in the blood (about 2·55 per cent.), lymph, and chyle. A variety of it, contained in solid muscular flesh, has been termed syntonin. Lehmann supposes it is formed in the organism from albumin, by the latter taking up oxygen. Until lately, fibrin was supposed to have the property of coagulating spontaneously, but recent researches by Dr Schmidt of Dorpat shew that its coagulation is due to the action upon it of another substance termed fibrino-plastic substance or globulin, a protein substance nearly related to albumin. The presence of air hastens the action.

3. *Casein.*—Composition in 100 parts—C53·8,H7·0,N15·1, O22·6,S1 (Moleschott). These numbers agree closely with the analyses of albumin, except that less sulphur is present in casein. It is slightly soluble in water, and it differs from albumin in the

solution not being coagulable by heat. It is precipitated by all acids, except carbonic acid, and is redissolved in excess. It is also precipitated by all earthy and metallic salts, and by potassium ferrocyanide. Casein constitutes the chief ingredient in the milk of the mammalia. It has also been found in very small quantity in morbid bile, in the fluid of cellular tissue, in flesh-juice, and in the small intestine of the human fœtus. It constitutes the envelope which surrounds the globules of oil or butter which float in milk. Rennet, which is an infusion of the mucous membrane of the fourth stomach of young calves, readily coagulates casein, the cause of this peculiar action being unknown.

4. *Myosin.*—This substance constitutes the gelatinous mass obtained by squeezing pulverised flesh from which all blood has been removed. The fluid part of muscle, or muscle-plasma, consists of myosin, or muscle-clot, and muscle-serum. Myosin gives the usual albuminoid reactions. It differs from blood fibrin in coagulating in a gelatinous mass,—not forming molecular fibres, as will be described in referring to the fibrous elements of the tissues. When myosin is dissolved in dilute acid, it becomes converted into another nearly allied substance, *syntonin.* Syntonin is insoluble in solution of sodium chloride, but in a ten per cent. solution of this salt, myosin is readily soluble. Syntonin is, however, not a special product of muscle, as it may be prepared by acting upon any albuminoid with hydrochloric acid.

5. *Globulin* or *Crystallin.*—Composition in 100 parts—C54·5,H6·9,N16·5,O20·9,S1·2 (Funke). This albuminous substance is found in the crystalline lens of the eye, and, according to some chemists, in the blood corpuscles. It forms a yellowish transparent mass when extracted from the lens by ether and alcohol. It is precipitated by all acids, including carbonic acid, and is redissolved by passing a stream of oxygen through it. According to Valenciennes and Frémy, the crystalline lens of fishes contains a substance called phaconin.

The Albuminoids constitute another group of substances nearly related to the albuminates, and no doubt derived from them. They are such bodies as Gelatin, Chondrin, Elastic stuff, or Elastin, Mucin, Pyin, Pepsin, and Ptalyin.

1. *Gelatin.*—Composition in 100 parts—C50·9,H7·2,N18·3, O and S23·6 (Gorup Besanez). It is obtained by boiling animal membranes, skin, tendons, &c., or by macerating bone in dilute

hydrochloric acid. When allowed to cool, it becomes a semi-solid, tremulous jelly, and if allowed to dry, it becomes elastic, vitreous, brittle, and hard. It is not precipitated by any acid except tannic acid. Though nearly allied to the protein compounds, it differs from them, and hence it has been found that animals fed exclusively on this substance die of starvation, as nutritive blood cannot be formed from it.

2. *Chondrin.*—Composition in 100 parts—C49·5,H7·1,N14·4, O and S28·9 (Gorup Besanez). This substance nearly resembles gelatin. It may be obtained by boiling permanent cartilage, such as those of the ribs or larynx. It is, when dry, a horny, hard, diaphanous substance. Solutions of it give a precipitate with all acids, alum, aluminium sulphate, plumbic acetate, and ferric sulphate,—thus differing in a remarkable manner from gelatin.

3. *Elastin.*—Composition in 100 parts—C55·65,H7·41,N17·74, O19·20 (Tilanus). This is found in ordinary yellow elastic tissue, of which it forms the chemical basis. It contains no sulphur. It is quite insoluble in boiling water, thus differing from white fibrous tissue, which yields gelatin on boiling.

4. *Mucin.*—Composition in 100 parts—C52·4,H7·0,N12·8, O27·8 (Scherer). This is the most important chemical constituent of mucus, the secretion of mucous membranes. Dilute acetic acid and mineral acid precipitate it. Heat produces no coagulation.

5. *Pyin.*—Composition in 100 parts—C51·69,H6·64,N15·09, O26·58 (Gorup Besanez). It is a constituent of pus, a pathological product the result of diseased actions of the animal body. It resembles mucin in its general characters, but differs in being precipitated by mercuric chloride.

6. *Pepsin.*—Composition in 100 parts—C56·7,H5·6,N21·1, O16·5 (Vogel). The active principle of the gastric juice is a ferment which acts powerfully on all protein bodies, forming derivatives which have received the name of peptones. It is prepared in great purity by treating an infusion of the glandular layer of the stomach with dilute tribasic phosphoric acid. Lime water is added, and the precipitate of calcic phosphate, along with the pepsin, is collected and treated with dilute hydrochloric acid. Having been again precipitated by lime water, the deposit is dissolved in dilute acid. To this second solution, a solution of cholestrin is slowly added, and the cholestrin, with the

pepsin entangled in it, is treated with ether. The ether dissolves out the cholestrin, and the remaining liquid is filtered. The filtrate contains the pepsin, with gives no precipitate with mineral acids, tannin, or mercuric chloride. Pepsin is most active in a dilute acid solution at the temperature of the human body. It is found in the urine, and Brücke found it in flesh.

7. *Ptyalin.*—This albuminous substance is the supposed ferment of the saliva. It contains sulphur. According to some physiological chemists, it converts starch, glycogen, &c., into sugar, by causing them to combine with water.

8. *Protagon* or *Myelin.*—This substance is distantly related to the albuminous substances above described. It is the chief constituent of nervous tissue, and is the parent of cerebrin, cerebric acid, &c. It may be extracted from brain-substance by ether and alcohol; but it is easier obtained from yolk of egg by the same reagents. When purified and well washed, it is a white substance, crystallising in acicular bundles. Its composition according to Liebreich, its discoverer, is $C_{116}H_{291}N_4PO_{22}$. Regarding the histological importance of this substance, see Molecular elements of the Tissues.

9. *Quinoidine.*—Another substance, named animal quinoidine, was discovered by Bence Jones and Dupré, in all animal tissues, especially in the crystalline lens. It resembles quinine in its chemical characters and optical properties.

ALBUMINOUS DERIVATIVES.—The albuminous principles above described, undergo a disintegrating process in the tissues, and the result of this process is the formation of a number of compounds, which are excreted from the body. They are—

1. *Glycocholic Acid.* — $C_{26}H_{45}NO_6$. In combination with sodium, this acid exists in large quantity in the bile. When obtained pure from ox bile, it crystallizes in bulky masses of white slender needles. It is not very soluble in hot or cold water, but is easily soluble in alcohol and ether. It turns the plane of polarization to the right.

2. *Taurocholic Acid.*—$C_{26}H_{45}NSO_7$. This acid exists as a sodium salt in the bile of most animals, along with glycocholic acid; but in the bile of the dog it occurs free from the latter. It occurs as very fine silky needles, which, when exposed to the air, rapidly change into an amorphous transparent mass. It

differs from glycocholic by containing sulphur, and by being *easily* soluble in water.

3. *Uric Acid.*—$C_5N_4H_4O_3$. This very important acid occurs in small proportion in the urine of man. It is always to be found in the juices of the spleen, liver, lungs, and brain. It exists in excess in gout, and in various forms of bodily derangement, attended by the formation of urinary calculi. It may be easily extracted from the urine of serpents, or from guano. When anhydrous, it forms small white crystalline scales, but with a little water of crystallization, it forms large crystals. It is very nearly insoluble in water. When heated dry it decomposes into hydrocyanic acid, cyanuric acid, ammonium cyanate, urea, and ammonium carbonate. Under the microscope, it presents various crystalline forms, as found in urine, but they are generally rhombs with the obtuse angles rounded off, and occasionally dumb-bell crystals. Uric acid is a product of the incomplete oxidation of the tissues. Its most remarkable characteristic, is the readiness with which it is acted on by all oxidising agents. In this way, numerous definite compounds are produced, the chief being alloxan, alloxantin, allantoin, and murexide. The relation existing between these substances, will be apparent on studying their chemical formulæ.

Uric acid,	$C_5N_4H_2O_3H_2$.
Alloxan,	$C_4N_2H_2O_4$.
Alloxantin,	$C_8N_4H_4O_7+3\ H_2O$.
Allantoin,	$C_4N_4H_6O_3$.
Murexide,	$C_8N_6H_8O_6$.

When uric acid is subjected to the action of an oxidising agent, in the presence of water, it gives up two of its atoms of hydrogen to the oxidising agent, while the remainder, termed dehyduric acid, reacts with water, to form mesoxalic acid and urea. Thus—

$$\underset{\text{Uric acid.}}{C_5N_4H_4O_3}+\underset{\text{Chlorine.}}{Cl_2}+\underset{\text{Water.}}{4\ H_2O}=\underset{\text{Mesoxalic acid.}}{C_3H_2O_5}+\underset{\text{Urea.}}{2\ CN_2H_4O}+\underset{\text{Hydrochloric acid.}}{2\ HCl}.$$

Those two atoms of urea are, however, formed at two successive stages of the process, the first of which result in the formation of alloxan, and the second in its decomposition. Thus—

$$\underset{\text{Dehyduric acid.}}{C_5N_4H_2O_3}+\underset{\text{Water.}}{2\ H_2O}=\underset{\text{Alloxan.}}{C_4N_2H_2O_4}+\underset{\text{Urea.}}{CN_2H_4O}.$$

$$\underset{\text{Alloxan.}}{C_4N_2H_2O_4}+\underset{\text{Water.}}{2\ H_2O}=\underset{\text{Mesoxalic acid.}}{C_3H_2O_5}+\underset{\text{Urea.}}{CN_2H_4O}.$$

By removing two atoms of hydrogen from mesoxalic acid or alloxan, other acids are formed. The numerous bodies which have been in this manner obtained from uric acid, upwards of forty in number, may, according to Odling,* who has paid much attention to this intricate subject, be classified into, 1. Simple non-nitrogenous acids, such as mesoxalic acid; 2. Bodies containing a residue of the acid, along with one residue of urea, or mon-ureides, such as alloxan; and, 3. Bodies containing a residue of the acid plus two residues of urea, or the di-ureides, such as uric acid. "Hydrated uric acid differs in composition from two atoms of urea by the addition of three atoms of carbonic oxide CO, capable of oxidation into carbonic anhydride CO_2, and by that oxidation of generating a certain amount of heat, or its equivalent of motion.

$$\underset{\text{Water.}}{2\,H_2O} + \underset{\text{Uric acid.}}{C_5N_4H_4O_3} + \underset{\text{Oxygen.}}{O_3} = \underset{\substack{\text{Carbonic}\\\text{anhydride.}}}{3\,CO_2}\quad \underset{\text{Urea.}}{2\,CN_2H_4O_2}.$$

"Hence uric acid must be considered to result from an incomplete oxidation of nitrogenous tissue, whereby, in addition to urea, carbonic oxide is produced, instead of carbonic anhydride." Reptiles, whose motions are sluggish and temperature slow, excrete carbonic oxide in the form of uric acid, or urate of ammonia; while mammals excrete perfectly burned carbonic anhydride. In the urine, uric acid is found in combination with ammonium and sodium. For crystals of uric acid and various urates, see Plate I., figs. 1, 2, 3, and 4, and description of plate.

4. *Urea.* COH_4N_2.—This substance is found in the urine of all mammals, especially in that of flesh eaters. It is also found in smaller quantity in the urine of birds and reptiles, and in the renal secretion of some animals of the lower orders. In a state of health, it exists in very minute quantity in the blood of man and of other animals, and it occurs occasionally in the perspiration, in the amniotic fluid, and even in the tissues. About 30 per cent. of the solid matter of the vitreous humour of the eye consists of urea. Considered chemically, it is isomeric with ammonium cyanate ($CNNH_4O$) and with carbamide ($N_2(CO)''H_4$), and it may be formed spontaneously by the transposition of the molecules of the former substance. The ammoniacal odour of

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* Lectures on Animal Chemistry, delivered at the Royal College of Physicians. By William Odling, M.B., F.R.S., &c. London, 1866.

decomposing urine is due to carbonate of ammonia, produced by the combination of water with urea, thus :—

$$\underset{\text{Urea.}}{COH_4N_2} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Ammonium carb.}}{(NH_4)_2\,CO_3}$$

Urea is formed as a product of the decomposition of many complex organic substances such as creatin, uric acid, allantoin, &c. Its presence in the body is due to the transformation of the tissues under the influence of the oxygen of the air absorbed in the lungs, and it is the last term in the series of the retrograde metamorphoses. When obtained pure, urea usually crystallizes in long flat prisms without terminal faces, but in certain circumstances it forms quadratic prisms terminated by octahedral faces. It tastes like saltpetre, dissolves in its own weight of cold water, very readily in hot water, easily in alcohol, but is nearly insoluble in ether. Urea forms three sets of compounds: 1, with acids; 2, with oxides and salts; and 3, various substitution derivatives called compound ureas. The most characteristic salt is the nitrate ($COH_4N_2.HNO_3$) which appears even in dilute solutions of urea, on the addition of a drop of nitric acid, in the form of rhombic or hexagonal plates, the acute angle of which, as measured by the goniometer = 82°. The appearance of this salt affords an excellent test for detecting the presence of urea in any fluid. The most important compound of urea with a salt is with mercuric nitrate, and Liebig's process for the volumetric estimation of urea is based on the precipitability of urea by mercuric nitrate, forming a compound, the composition of which is represented by the formula $COH_4N_2\ 2\ HgO$.

5. *Hippuric Acid.* $C_9H_9NO_3$ (Pl. I. fig. 5).—This acid exists in very small quantity in the urine of man, but it is found abundant in that of herbivorous animals. According to Dr Bence Jones, the urine of a healthy man contains from 0.03 to 0.04 per cent. of this substance. When benzoic acid is taken internally, hippuric acid speedily appears in the urine. This acid forms colourless transparent prisms, often of considerable size.

6. *Inosinic Acid.* $C_5H_8N_2O_6$ (?)—It is doubtful whether this acid, first isolated by Liebig, really exists as such in the body, but it is undoubtedly one of the derivatives of the albuminous group. It was found in the mother liquor of the preparation of creatin from flesh-juice, and appeared as an un- crystallisable substance, very soluble in water, and having a flavour of broth.

7. *Xanthin* or *Xanthic Oxide.* $C_5H_4N_4O$.—This body occurs in a species of urinary calculus, and, according to Scherer, it is a normal constituent of the human body. It differs from uric acid only by one atom of oxygen, uric acid having O_3 while xanthic oxide contains only O_2. It may be prepared artificially from uric acid, from guanin, from muscular flesh, and from urine. It is a white scaly substance, nearly insoluble in water, and insoluble in alcohol and ether.

8. *Hypoxanthin* or *Sarcin.* $C_5H_4N_4O$.—This substance is a weak organic base, existing in muscle-juice, and only in small quantity. A substance very similar to it has been found in human urine, but chemists are not agreed whether this substance is really sarcin or guanin. It is obtained from the mother liquor in the preparation of creatin, and is a white crystalline powder.

9. *Cystin* or *Cystic Oxide.* $C_3NH_7SO_2$.—(Pl. I. fig. 6.)—This organic base is found in a very rare form of urinary calculus occurring in men and dogs, and when separated, is seen to be a yellowish, shining, confusedly crystalline substance, tasteless, neutral, insoluble in alcohol and water. It is remarkable for containing sulphur.

10. *Taurin.* $C_2H_7NSO_3$ (Pl. I. fig. 7 *a*).—This remarkable substance was first obtained from oxbile and hence its name: from *taurus*, a bull. It results from the transformation of taurocholic acid under the influence of acids and alkalies.

$$\underset{\text{Taurocholic acid.}}{C_{26}H_{45}NSO_7} + \underset{\text{Water.}}{H_2O} = \underset{\text{Taurin.}}{C_2H_7NSO_3} + \underset{\text{Cholic acid.}}{C_{24}H_{49}O_5}$$

Fresh bile is clarified from mucus by the addition of an acid, and filtered; boiled with hydrochloric acid; the decanted liquor evaporated nearly to dryness on the water bath, and the mother liquor extracted with alcohol. The liquid on cooling, yields taurin in the form of six-sided prisms, terminated by four and six-sided pyramids like those of common quartz. It has a cool taste, is soluble in water, but insoluble in alcohol and ether. It is remarkable for containing more than 25 per cent. of sulphur. When burned, fumes of sulphurous anhydride are evolved. Taurin is nearly related to isthionate of ammonium, one molecule of this substance, minus a molecule of water, yielding a molecule of taurin. It is never found in the free state in healthy bile, or in any other secretion.

11. *Allantoin.* $C_4H_6N_4O_3$.—(Pl. I. Fig. 8.)—This substance is one of the derivatives of uric acid, and may be artificially pre-

pared from it. It exists in the amniotic and allantoic fluids, and when isolated, is found to present the form of shining colourless prisms, very soluble in water, and also in alcohol.

12. *Tyrosin.* $C_9H_{11}NO_3$ (Pl. I. fig. 9).—This substance occurs ready formed, and always accompanied by leucin, in the liver and blood of the hepatic vein in certain states of liver-disorder; and it has also been discovered in the spleen and pancreas. Occasionally it is found in the urine, and it may result from the decomposition of any albuminoid substance under the action of acids, alkalies, or putrefactive changes. Artificially, it has been prepared from casein, from horn, and from cochineal. It crystallises from aqueous solutions in stellate groups of long slender needles, having a beautiful silky lustre, soluble in water, in alcohol, but not in ether. It forms definite compounds with acids and alkalies, and there are several derivatives of more interest to the chemist than to the physiologist.

13. *Leucin.* $C_6H_{13}NO_2$ (Pl. I. fig. 10).—First discovered in old cheese, leucin has since been found, associated with tyrosin, in the liver in certain forms of disease of that organ. It also occurs in the lung-tissue, in the thyroid and thymus glands, and especially in the pancreas. It may be obtained by the action of sulphuric acid upon gelatin, muscular flesh, legumin, wool, white of egg, horn, &c.; and when purified, it presents the appearance of soft nacreous scales, somewhat resembling cholestrin. When found in urine, it forms yellow-coloured balls. (See Pl. I. fig. 10.) It is sparingly soluble in cold, but readily in hot water; sparingly in alcohol, and insoluble in ether. It forms definite compounds with acids and bases.

14. *Glycocin* or *Glycocol.* $C_2H_5NO_2$.—This substance is sometimes called sugar of gelatin, on account of its sweetish taste, and its being produced by the action of caustic alkalies on gelatin or meat. It exists in glycocholic acid, one of the bile acids, which, when acted on by an alkali, is resolved into glycocin and cholic acid.

$$\underset{\text{Glycocholic acid.}}{C_{26}H_{43}NO_6} + \underset{\text{Water.}}{H_2O} = \underset{\text{Glycocin.}}{C_2H_5NO_2} + \underset{\text{Cholic acid.}}{C_{24}H_{40}O_5}$$

It may also be obtained from hippuric acid. It crystallises readily in flattened prisms or aggregated plates. It is sparingly soluble in water, slightly soluble in hydrated alcohol, insoluble in ether. It differs from taurin in being sweet instead of bitter, and in not containing any sulphur.

15. *Creatin.* $C_4H_9N_3O_2$ (Pl. I. fig. 11).—This important substance is nearly allied to creatinin, differing from it only by the elements of water. It has not yet been settled whether or not creatin, as such, exists in the body, or whether it results from the decomposition of creatinin in the process of preparation. These two substances may be easily converted one into the other, the action of acids changing creatin into creatinin, while the action of alkalies, creatinin into creatin. Liebig and Dessaignes are both of opinion that the creatin of muscular flesh is produced by the decomposition of creatinin. It has been found in the urine, in the blood, and, by Städeler, in the brains of pigeons and dogs. It may be prepared by making an aqueous extract of beef, evaporating in vacuo, exhausting the residue with alcohol, and the alcohol evaporated till the creatin crystallises out. Anhydrous creatin is an opaque white mass, inodorous, somewhat bitter, neutral. The hydrate of creatin is in the form of clear prisms. It is soluble in water and alcohol, but not in ether. According to Strecker, creatin may be regarded chemically as a compound of cyanamide (*i. e.*, urea *minus* water) and sarcosin. It is a very weak base.

16. *Creatinin.* $C_4H_7N_3O$ (Pl. I. fig. 12).—This substance exists in the urine to the amount of 0·5 per cent., in muscular flesh, and in blood. It may be extracted from any of these substances, and also by the action of strong mineral acids on creatin. It occurs in the form of colourless prisms. It tinges reddened litmus paper blue, and is soluble in water and in alcohol.

2. The Fatty Principles and their Allies.

The fatty principles are divided into, 1. True fats ; 2. Amyloid substances and sugars ; and, 3. Acids related to sugar.

1. True Fats.—The term fat was originally applied to all substances containing carbon, hydrogen, and a small amount of oxygen, which form oily liquids or greasy solids, leave a permanent stain on paper, burn with a bright flame with little or no soot, are insoluble in water, but soluble in alcohol and ether. The researches of Chevreul,* however, shewed that fatty substances may be subdivided into (1) non-saponifiable fats ; (2) saponifiable fats ; and (3) fatty acids or soap acids. He shewed that certain

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* Chevreul, "Recherches sur les corps gras d'origine animale." Paris, 1823.

fats (the non-saponifiable) undergo no change when boiled with alkalies, while others (the saponifiable) formed soaps when treated with aqueous alkalies or with certain heavy metallic oxides. The formation of a soap when a saponifiable fat is treated with an alkali or metallic oxide is called saponification and consists of the resolution of the fat into two products, viz., First, a fatty acid which combines with the alkali and forms the soap; and, secondly, almost invariably, the substance called glycerin, a sweetish, clear, transparent fluid. These researches have since been confirmed and extended by those of Berthelot.*

A fat is a body of the type of three atoms of water condensed to one, thus—

$$\left.\begin{matrix}H_3\\H_3\end{matrix}\right\}O_3$$

in which three of the atoms of hydrogen are replaced by the triatomic radicle glyceryl, and three others by three atoms of any fatty acid radicle. Tristearin, for example, a fat abounding in beef and mutton suet, has this formula—

$$\begin{array}{ll}\text{3 monatomic atoms of stearyl} \;\; . & \left\{\begin{array}{l}(C_{18}H_{35}O)\\(C_{18}H_{35}O)\\(C_{18}H_{35}O)\end{array}\right. \\ \text{1 triatomic atom of glyceryl} \;\; . & \;\;(C_3\,H_5)\end{array}\left.\vphantom{\begin{array}{l}a\\a\\a\\a\end{array}}\right\}O_3.$$

1. *The non-Saponifiable Fats* are cholestrin and serolin. These substances remain perfectly unaltered after prolonged boiling with solution of caustic potash (KHO).

(*a*) *Cholestrin.* $C_{26}H_{44}O$ (Pl. I. fig. 13).—This fatty substance sometimes constitutes nearly the entire bulk of human gall stones. It has been found in the bile, in the blood, in the brain, in the yoke of egg, and in certain morbid products of the human body. It is readily prepared by crystallising pulverised biliary calculi from boiling alcohol. It is white, inodorous, tasteless, insoluble in water, readily soluble in hot alcohol, from which it is deposited in beautiful soft nacreous laminæ. It forms compound ethers when heated with acetic, butyric or stearic acids, shewing that it partakes of the nature of an alcohol.

(*b*) *Serolin.*—Boudet gave this name to a fat which he obtained by the action of ether upon dried blood serum. It is, according to this chemist, amorphous, but Verdeil and Marcet state that it crystallises in nacreous laminæ. Some chemists consider this substance to be merely a mixture of several fats of different melting points.

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* Berthelot, "Chemie organique fondèe sur la synthèse."

2. *The Saponifiable Fats* are very numerous, but the most important are stearin, margarin, and olein. When boiled with an alkali they are decomposed into an acid which, uniting with the alkali, forms a soap, glycerin being set free and rising to the surface. Considered chemically, they are the compound ethers of the triatomic alcohol glycerin, hence they have received the name of glycerides.

a. Stearin is a white crystallisable fat (Plate I. fig. 14), constituting the chief part of fat, soluble in about seven times its weight of boiling alcohol, and much more freely in hot ether. It exists in three modifications, differing from each other in the fusing point. These are termed monostearin, distearin, and tristearin. They are ethers formed from glycerin, by the replacement of one, two, or the whole of the atoms of the typical hydrogen of glycerin, by the monatomic radicle stearyl ($C_{18}H_{35}O$.)

$$\begin{array}{ccc} \text{Monostearin.} & \text{Distearin.} & \text{Tristearin.} \\ \left.\begin{array}{c} (C_3H_5) \\ C_{18}H_{35}O \\ H_2 \end{array}\right\} O_3 & \left.\begin{array}{c} (C_3H_5) \\ 2(C_{18}H_{35}O) \\ H \end{array}\right\} O_3 & \left.\begin{array}{c} (C_3H_5) \\ 3(C_{18}H_{35}O) \\ \end{array}\right\} O_3 \end{array}$$

Among the numerous decompositions of stearin, the most interesting, from a physiological point of view, is that discovered by Bernard, namely, that stearin, mixed with pancreatic juice, yields an emulsion in which all the stearin is resolved into stearic acid and glycerin.

b. Margarin. $C_{54}H_{104}O_6$ (Plate I. fig. 15).—This substance constitutes one of the solid ingredients of human fat. When extracted by boiling alcohol, it crystallises in pearly scales or clusters formed of needles, which are fusible at about 47° C. Various chemists have isolated from fat a substance resembling this, and it is now generally believed that margarin is not a simple fat, but a mixture of palmitic and stearic acids. No ethers corresponding to the stearic ethers, already mentioned, have yet been obtained.

c. Olein.—Pure olein is colourless, and is a fluid even at freezing point. When exposed to the air, it is resenoid in appearance. Chevreul prepared it by boiling human fat in a flask, filtering after leaving the solution for twenty-four hours, concentrating, adding water, which separates the olein, exposing the product to cold, and separating the liquid from the solid portion by pressure. Resembling stearin, it occurs in three modifications, which are ethers of glycerin, in which one or more of the typical atoms of hydrogen are replaced by the radicle oleyl ($C_{18}H_{33}O$) as follows:—

$$\underset{\text{Monolein.}}{\left.\begin{array}{c}(C_3H_5\\(C_{18}H_{33}O)\\H_2\end{array}\right\}O_3}\qquad\underset{\text{Diolein.}}{\left.\begin{array}{c}(C_3H_5)\\2(C_{18}H_{33}O)\\H\end{array}\right\}O_3}\qquad\underset{\text{Triolein.}}{\left.\begin{array}{c}(C_3H_5)\\3(C_{18}H_{33}O)\end{array}\right\}O_3}$$

3. *The Fatty Acids.*—These bodies are obtained chiefly by the saponification of saponifiable fats. They combine with bases to form salts, and may be separated therefrom in their original state by stronger acids. Stearic and palmitic acids may be taken as the type of one series of the fatty acids in which the general formula is $C_nH_{2n}O_2$; oleic acid is the type of a second series, the general formula of which is $C_nH_{2n-2}O_2$. A third series, having the general formula, $C_nH_{2n-2}O_4$, may be obtained by the oxidation of the two preceding groups—oxalic acid being an example. The following is a list of these fatty acids, arranged in the three groups just indicated:—

Stearic Acid Group. $C_nH_{2n}O_2$		*Oleic Acid Group.* $C_nH_{2n-2}O_2$		*Oxalic Acid Group.* $C_nH_{2n-2}O_4$	
Formic .	$C\ H_2\ O_2$			Oxalic .	$C_2\ H_2\ O_4$
Acetic . .	$C_2\ H_4\ O_2$			Malonic	$C_3\ H_4\ O_4$
Propionic	$C_3\ H_6\ O_2$	Acrylic .	$C_3\ H_4\ O_2$	Succinic	$C_4\ H_6\ O_4$
Butyric .	$C_4\ H_8\ O_2$			Lipic .	$C_5\ H_8\ O_4$
Valeric .	$C_5\ H_{10}O_2$	Angelic .	$C_5\ H_8\ O_2$	Adipic	$C_6\ H_{10}O_4$
Caproic .	$C_6\ H_{12}O_2$			Pimelic	$C_7\ H_{12}O_4$
Œnanthylic	$C_7\ H_{14}O_2$			Suberic	$C_8\ H_{14}O_4$
Caprylic .	$C_8\ H_{16}O_2$			Anchoic	$C_9\ H_{16}O_4$
Pelargonic	$C_9\ H_{18}O_2$			Sebaic .	$C_{10}H_{18}O_4$
Rutic . .	$C_{10}H_{20}O_2$				
Lauric . .	$C_{12}H_{24}O_2$				
Myristic .	$C_{14}H_{28}O_2$				
Palmitic .	$C_{16}H_{32}O_2$	Physetoleic	$C_{16}H_{30}O_2$		
Stearic .	$C_{18}H_{36}O_2$	Oleic .	$C_{18}H_{34}O_2$		
Arachidic.	$C_{20}H_{40}O_2$				
Cerotic .	$C_{27}H_{54}O_2$				
Melissic .	$C_{30}H_{60}O_2$				

a. The Stearic Series of Fatty Acids.

1. *Formic acid*—CH_2O_2—has been found in the blood, in the

urine, in the fluid of the spleen, in muscle-juice, and in the perspiration.

2. *Acetic acid*—$C_2H_4O_2$—probably exists in several of the animal secretions, but it usually results from the decomposition and oxidation of organic bodies.

3. *Butyric acid*—$C_4H_8O_2$—is found in perspiration, in muscle-juice, and, in combination with glycerin, in butter. When butter becomes rancid, it has a peculiar odour, produced by free butyric acid. It is a pure, colourless, transparent liquid.

4. *Valeric acid*—$C_5H_{10}O_2$—is a frequent product of the oxidation of fats, and of the putrefaction of albuminous substances.

5. *Caproic* ($C_6H_{12}O_2$), *Caprylic* ($C_8H_{16}O_2$), and *Rutic* ($C_{10}H_{20}O_2$) *acids* exist in butter in combination with glycerin.

6. *Palmitic acid*—$C_{16}H_{32}O_2$—is universally distributed in the fats of the animal kingdom, and has been obtained by Chevreul by the saponification of human fat.

7. *Stearic acid*—$C_{18}H_{36}O_2$—is the most important of the fatty acids of the group to which it gives its name. It was discovered by Chevreul as a constituent of the solid fats, especially in beef and mutton suet, but it is also to be found in butter, in human fat, in the fat of the goose, serpents, &c. It may be prepared by the saponification with soda-ley of beef or mutton suet, decomposing the soap with water and dilute sulphuric acid, and dissolving the acid in hot alcohol. When allowed to crystallise from such a solution, it falls as nacreous laminæ or needles, is tasteless, inodorous, and is distinctly acid. It forms stearates with bases, substitution compounds with chlorine and bromine, and a series of ethers.

8. *Propionic, Œnanthylic, Pelargonic, Lauric, Myristic, Arachidic, Cerotic, and Melissic acids* have never been found in the human body.

b. The Oleic Series of Fatty Acids.

Oleic acid—$C_{18}H_{34}O_2$—is the most important member of this series. It is difficult to isolate it owing to its tendency to combine with oxygen. It is obtained by saponifying the non-drying oils, such as almond oil, and solid fats. It crystallises from an alcoholic solution in dazzling white needles.

c. The Oxalic Acid Series.

Oxalic acid forms the lowest, and sebaic acid the highest, term of this group.

1. *Oxalic acid*—$C_2H_2O_4$—in combination with calcium as calcium oxalate (CaC_2O_4), is often found in the urine, in urinary deposits, and calculi, in the allantoic fluid, and in the mucus of the gall bladder. It occurs in the form of square-based, octahedral crystals, and occasionally in the form of dumb-bells. (Plate I. fig. 17.) Recent researches have shewn that oxalic acid is nearly related, in chemical constitution, to many of the derivatives of uric acid already noticed. Many of these bodies may be regarded as amides (or ammonia substitution compounds) of oxalic acid—being derived from two or more molecules of oxalic acid by addition of ammonia and abstraction of water. As these processes may indicate what takes place in the living body, a few examples are here given.

$$2C_2H_2O_4 + 2NH_3 - 4H_2O = C_4H_2N_2O_4$$

Oxalic acid. Ammonia. Water. Alloxan.

On introducing a molecule of another acid, we have decompositions like the following:—

$$C_2H_2O_4 + CO_2 + 2NH_3 - 3H_2O = C_3H_2N_2O_3$$

Oxalic acid. Carbonic. Anhydride. Ammonia. Water. Parabanic acid.

$$2C_2H_2O_4 + CH_2O_2 + 4NH_3 - 7H_2O = C_5H_4N_4O_3$$

Oxalic acid. Formic acid. Ammonia. Water. Uric acid.

$$C_2H_2O_4 + CH_2O_2 + CO_2 + 4NH_3 - 5H_2O = C_4H_6N_4O_3$$

Oxalic acid. Formic acid. Carbonic. Anhydride. Ammonia. Water. Allantoin.

2. *Adipic acid* has been prepared by the action of nitric acid upon suet. None of the other acids of this series have been found in the human body.

The fatty acids are physiologically important, 1st, On account of their adhesive affinities ; 2d, by developing heat in consequence of their property of oxidising at a low temperature, forming carbonic acid and water, which, if too abundant, are readily removed from the system ; and, 3d, by their power of conducting heat. Although we daily consume a large amount of these acids, yet they are not excreted as such, nor do they form fats.

GLYCERIN. $C_3H_8O_3$.—This is the other substance which is produced in the process of saponification. It does not exist ready formed in fats, but is produced from them, together with a fatty acid, by addition of the elements of water. Glycerin is really a triatomic alcohol, and bears the same relation to the fats, stearin and olein, &c., as alcohol bears to the compound ethers, one, two, or three of the atoms of hydrogen being replaceable by acid radicles, producing fatty or oily compounds. It is an uncrystallisable, syrupy liquid,—colourless, inodorous, sweet, neutral. It dissolves in water, in alcohol, and in chloroform, but not in ether.

ORIGIN OF FAT.—The origin of fat in animal bodies has given rise to considerable discussion. 1st, It may enter the body ready formed in the food, whether animal or vegetable ; 2d, Animals seem to have the power of transforming various substances into fat. Geese fed on grain become fat, bees form wax, a species of fat, from flowers. Thus, says Liebig, the herbs and roots consumed by the cow contain no butter ; in the hay and fodder of oxen, no beef-suet exists ; and no hog's lard can be found in the potatoes given to swine. The masses of fat found in the bodies of these animals are formed in their organism, and this, according to Liebig, takes place by non-nitrogenous substances yielding up their oxygen. Dumas, however, states that the Indian corn or maize on which a goose is fed contains 9 per cent. of fat, and on calculating the quantity consumed, he found more fat in it than was sufficient to explain the increased weight of the goose. These conclusions were confirmed by the careful and extensive observations of Boussingault. Liebig, however, to support his position, made several very ingenious experiments upon swine. He says that three pigs, to be fattened in thirteen weeks, require 1000 lbs. of pease, and 6825 lbs. of boiled potatoes. These contain together 26 lbs. of fat,—21 lb. in the pease, and 5 lb. in the potatoes. One fattened pig gives on an average 50 to 55 lbs. of fat ; that is, the three together, 150 to 165 lbs. Each animal, before being fattened, contains, on an average, 18 lbs. of fat ; that is, 54 lbs. for the three. If to these 54 lbs. we add 26 lbs. from the food, we get 80 lbs ; and if we substract these from 150 lbs. to 165 lbs., there is a remainder of 70 to 85 lbs. of fat produced from the starch, &c., contained in the food. These experiments have been confirmed by the more recent researches of Messrs Lawes and Gilbert,* who found that, in fattening pigs, for every 100 parts of fat in the food, the animals stored up from 400 to 450 parts of fat in their bodies. The origin of fat, therefore, in the living body is threefold,—1st, It is derived ready formed from plants ; 2d, It is formed in the absence of oxygen, or where oxygen is deficient, by the deoxidation of starch, gum, and sugar, which thus supplies the oxygen wanted; and, 3d, By decomposition of the albuminous compounds, the actual character of which is not yet clearly ascertained.

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* Lawes and Gilbert. *Philosoph. Trans.* 1859, p. 543.

2. Amyloid Substances and Sugars.—The non-nitrogenous substances which, by yielding up oxygen, become transformed into fatty compounds, or are nearly related in chemical composition to fatty compounds, are as follows:—Glycogen, starch, and the different varieties of sugar.

1. *Glycogen.* $C_6H_{10}O_5$.—Animal starch, animal dextrin, hepatin. This substance, isomeric with starch, occurs in the liver and in the placenta, and is believed to enter largely into the composition of the tissues of the embryo. It occurs in three forms, of which one, of the formula $C_6H_{10}O_5$, is powdery, two others, $C_6H_{12}O_6$ and $C_6H_{14}O_7$, are gummy. It is easily prepared by making a decoction of fresh liver, filtering, and precipitating the filtrate with alcohol of 38 to 40 per cent. When dried, it is a white, mealy powder, neutral, inodorous, and tastes like starch. It polarizes to the right four times more intensely than dextrose sugar. Iodine colours it violet or bright brown-red, seldom pure blue. All re-agents which transform starch into sugar similarly affect glycogen, and the sugar so produced is identical with grape sugar. The ferments of the saliva, liver, and pancreas readily effect this transformation. The important physiological relations of this substance, as discovered by the labours of Bernard, Pavy, M'Donnell, Harley, &c., will be fully considered when treating of the functions of the liver.

2. *Starch.* $C_6H_{10}O_5$.—True starch is now known to exist as a constituent of the human body. (Busk, Carter.) Many of the granules, however, termed *corpora amylaceæ*, found in the brain, spinal cord, liver, spleen, kidneys, and mucous membranes, though resembling starch corpuscles in form, do not give a blue reaction with iodine, even with the addition of a little sulphuric acid, and differ from it in chemical composition. To such bodies I have for a long time given the name of *amyloid.* Starch is of great physiological importance, inasmuch as it constitutes a large proportion of human food. Infusions of almost any of the animal tissues, and saliva, and pancreatic juice, readily convert it into sugar.

3. *Sugars.*—Under this name are included a number of

organic compounds, which are soluble in water, crystallisable, have a sweet taste, neutral reaction, and in a state of solution rotate the plane of vibration of a ray of polarised light. Those of interest to the physiologist are, *a.* Saccharose, or cane sugar; *b.* Lactose, or milk sugar; *c.* Glucose, or grape sugar; and, *d.* Inosite, or muscle sugar.

a. Saccharose, or Cane Sugar. $C_{12}H_{22}O_{11}$.—This substance is not found in the animal body, but it is widely diffused in the vegetable kingdom, and forms an important element in the food of man. It crystallises in large monoclinic prisms, is soluble in water, insoluble in alcohol and ether, and the aqueous solution turns the ray of polarised light to the right.

b. Lactose, or Milk Sugar. $C_{12}H_{22}O_{11}$.—This sugar is found only in the milk of the mammalia. It may be obtained from milk by precipitating the casein by acid or rennet, filtering, and evaporating the whey to the crystallising point. It occurs as hemihedric trimetric crystals, and the aqueous solution turns the plane of polarised light to the right. It differs from cane sugar in crystalline form.

c. Glucose, or Grape Sugar. Diabetic sugar, sugar of urine, &c., $C_6H_{12}O_6+H_2O$.—This substance exists in the liver, in the amniotic and allantoic fluids, in the blood, in the chyle, and in eggs. In the disease called diabetes this sugar is found in the urine often to the amount of 8 or 10 per cent.; and according to Bence Jones it exists in minute quantity even in healthy urine. Compounds of glucose are likewise found in the animal body. When gelatin, hyaline cartilage, and rib-cartilage are boiled with hydrochloric acid, large quantities of glucose are obtained. It may be obtained by evaporating the urine of diabetic patients, and may be purified by re-crystallisation from a solution in boiling alcohol. From an aqueous solution it is deposited in white, opaque, granular, hemispherical masses, consisting of the hydrate, $C_6H_{12}O_6+H_2O$.; but from nearly absolute alcohol it is obtained as anhydrous, microscopic, sharply defined needles. It is less soluble in water than cane sugar, and it rotates the plane of polarised light 53·2° to the right. It gives a dark brown colour with liquor potassæ (Moore's test), and has the power of immediately reducing cuprous oxide from an alkaline solution of cupric sulphate (Trommer's test). Its quantitative estimation is made by the amount of cuprous oxide thrown down from a known measure of potassio-tartrate of copper (Fehling's test). The potassio-tartrate of copper, made alkaline by the addition of a little liquor potassæ, is heated to boiling in a capsule, and the liquid containing sugar is dropped in until the copper solution acquires a pale straw colour by the separation of red cuprous oxide.

d. Inosite, or Muscle Sugar. $C_6H_{12}O_6$ (Pl. I. fig. 16).—This substance, isomeric with glucose, exists in the muscular substance of the heart, in the lungs, kidney, liver, and spleen. It is best prepared from the muscle of the heart. It crystallises in tabular plates, or oblique prisms, or right rhombic prisms, containing two atoms of water of crystallisation. Inosite has a sweet taste, and no rotatory power, differing in the latter respect from the other sugars.

3. Acids related to Sugar.—Nearly allied to the starch and sugar group of compounds just described are the two substances known as lactic and sarcolactic acids, the former existing in sour milk, the latter in muscle-juice.

1. *Lactic acid.* $C_3H_6O_3$.—This acid is the result of a peculiar fermentation, the lactic acid fermentation, of various kinds of sugar, preceding the butyric acid fermentation. The change of milk sugar into lactic acid is shewn by the following equation :—

$$\underset{\text{Milk sugar.}}{C_{12}H_{22}O_{11}} + \underset{\text{Water.}}{H_2O} = \underset{\text{Lactic acid.}}{4C_3H_6O_3}$$

2. *Sarcolactic acid.* — When this acid was discovered by Berzelius in the juice of muscular flesh, he imagined it to be identical with the lactic acid of sour milk, but Liebig shewed that though the acids are hardly to be distinguished, their calcium and zinc salts exhibit marked distinctions. This acid gives the acid reaction exhibited by muscle after it has been fatigued by contractions induced in any way.

3. THE MINERAL PRINCIPLES.

The mineral or inorganic principles found in the human body may be classified as follows :—

1. Gases.—*Oxygen* (O) and *nitrogen* (N) exist in a free state in the blood and in the urine.

Hydrogen (H) is never found in a free state, but exists in water, and in light carburetted hydrogen (CH_4).

Light carburetted hydrogen (CH_4) has been found along with other gases in the flatus from the intestinal canal.

2. Free Acids.—*Carbonic acid* (CO_2), or as it is now called, carbonic anhydride, exists in both venous and arterial blood, especially in the latter.

Sulphuric acid (H_2SO_4) does not exist free in the body, but forms sulphates, which may be either neutral or acid, by combining with various bases.

Silicic acid (SiO_2) has been found in several tissues.

Hydrochloric acid (HCl) occurs in a free state in the gastric juice.

3. Salts.—1. *Carbonates.—Sodium carbonate* ($Na_2CO_3+10H_2O$) and *potassium carbonate* (K_2CO_3) exist in urine, and probably in the blood and tissues. *Ammonium carbonate* (NH_4HCO_3) is said to be found in expired air, but as a normal product, its presence is doubtful. *Calcium carbonate* ($CaCO_3$) exists in the bones and teeth, and it also occurs as a urinary sediment. In the urine of man it is very rare, but is common in that of the horse, where it forms peculiar globular bodies, identical with the artificial calculi made by Mr Rainey, which will be described in treating of the molecular elements of the tissues. *Magnesium carbonate* ($MgCO_3$) also exists in bones, teeth, and urine.

2. *Chlorides.*—The *chlorides of sodium* ($NaCl$) and *potassium* (KCl) exist in large quantity in all the solids and fluids of the body. Sodium chloride is the more abundant of the two. Potassium chloride is found chiefly in muscle-juice. *Ammonium chloride* (NH_4Cl) is found in the saliva, in tears, and in the urine.

3. *Oxalates.—The oxalate of calcium* (CaC_2O_4) is found in the urine in certain states of the system. It forms octahedral crystals and dumb-bells (Pl. I. fig. 17).

4. *Fluorides.—Fluoride of Calcium* ($CaFl$) exists in small quantity in bones, in teeth, and in the blood. It is found chiefly in enamel, which owes its great hardness to this salt.

5. *Phosphates.*—The *phosphates of sodium* are found in all the solids and fluids of the body. They are three in number, the basic ($Na_3PO_4+12H_2O$), the neutral ($Na_2HPO_4+12H_2O$), and the acid ($NaH_2PO_4+H_2O$). They exist largely in the blood, and recent investigations shew that in the process of respiration they carry the carbonic acid, in a loose state of combination, from the tissues to the lungs, there to be eliminated. In like manner, the basic *phosphate of potassium* ($K_3PO_4+12H_2O$), the neutral ($K_2HPO_4+12H_2O$), and the acid ($KH_2PO_4+H_2O$) are found in every part of the body. The neutral, or tribasic *phosphate of*

calcium (Ca_32PO_4) forms the chief part of the earthy matter of bone. It exists in considerable quantity in teeth, and is found in all the solids and fluids of the body. The *phosphate of magnesium* ($HMgPO_4+7H_2O$), exists in the blood, in the urine, and generally, though to a comparatively small amount, in the tissues. The *ammonia-magnesic phosphate* ($MgNH_4PO_4 +6H_2O$) is frequently met with as a constituent of urinary calculi, and is always formed during the alkaline fermentation of urine. It occurs as large, transparent, rhombic prisms, but it is sometimes peniform or feathery in its appearance (Pl. I. fig. 18).

6. *Sulphates.*—The *sulphates of sodium* ($Na_2SO_4+10H_2O$), of *potassium* (K_2SO_4), and of *calcium* ($CaSO_4$), are found everywhere, specially in the blood and urine. *Sulphate of calcium* exists largely in bone.

7. *Sulphocyanides.*—The *sulphocyanide of potassium* (KCNS) is found only in the saliva, and in very small quantity.

4. Metals.—The presence of iron, manganese, copper, and lead have been already noticed (p. 5). The state of combination in which these metals exist in the body is quite unknown. Of these, iron is the most important.

The mineral ingredients above described enter the body of man in his food and drink. They all exist, more or less, in the ordinary articles of food ; and even pure water, the natural drink of man, contains many of them in a state of solution. For instance, if a man were to consume two lbs. of potatoes and two lbs. of bread daily, no less than half an ounce of solid tribasic phosphate of calcium would enter his system in twenty-four hours. The salts are chiefly excreted by the kidneys and alvine evacuations, but every secretion contains more or less of them, so that it is possible to judge of the amount of mineral matter which enters the frame from the quantity which leaves it. They are given off by the emunctories in proportion to the amount introduced, so that a healthy state of the economy is preserved. Some mineral substances pass through the body and appear in the urine unchanged, such as the alkaline carbonates, sulphates, nitrates, phosphates, borates, chlorates, silicates, &c. ; while others are changed, such as salts of ammonia, which may be converted into nitrates. The neutral salts of the organic acids are converted into carbonates.

Irregularities of food must modify the amount of mineral matter taken into the system. These mineral matters are usually soluble, but only to a certain extent. If then they be in excess, so that the natural fluid containing them is more than saturated, they are partly precipitated and give rise to concretions. A diminution of the fluid of the secretion would of course produce the same result. Occasionally, insoluble salts are formed, which are deposited from one or other of the excretions, an example of which is seen in the octahedral crystals of oxalate of lime found in the urine.

5. Water (H_2O) forms 70 per cent. of the whole body. It is an important constituent of all the solids and fluids. It is chiefly derived from without, in the food or drink, but a small quantity is formed within the body by the oxidation of the hydrogen of organic compounds.

4. Pigmentary Principles.

In animals, colour depends on two circumstances: first, the deposition of pigment; and, second, on purely optical phenomena, originating in peculiarity of structure. Of some insects, as the cochineal-insect, *Coccus cacti*, the entire substance is used as a dye; certain of the animal fluids, as the blood, bile, and urine are also strongly coloured. Pigments rarely exist in animals in the separate state, and their separation is a matter of great difficulty.

Pigment exists more or less in the rete mucosum of the skin of all races of men, and its amount and character determines the colour peculiar to each race. In the negro race, black pigment abounds; in the Indian, red; the Malay, yellow or brown; and so on. In proportion as the race is more and more fair, the individual varieties of complexion due to this cause are more pronounced. Thus, there is often a more striking difference between the complexion of two individuals, Europeans, than can be found between two negroes. Occasionally, individuals of white races are met with having an unusually large amount of pigment in the skin, either generally diffused, or located in one or more spots. A black pigment is also found in the lungs of old persons, and in those working in coal mines, or living in a mining district. The nature of the cutaneous pigment found in man has still to be examined, but in the lungs it consists of pure carbon.

Black pigment, termed *melanin*, is found in the cells of the choroid of the eye. This pigment (melanin) (Pl. I. fig. 24), and the black pigment found in a cancerous tumour, have been analysed by Scherer, Rosow, and Heintz, with the following result :

Melanin of the choroid.				*Melanin of tumour.*	
Scherer.		Rosow.		Heintz.	
C.	58.28	C.	54.0	C.	53.44
H.	5.92	H.	5.3	H.	4.02
N.	13.77	N.	10.1	N.	7.1
O.	22.03	O.	30.0	O.	35.44
		Ash	0.6		
	100.00		100.0		100.00

We shall now describe, 1. The pigments of the blood ; 2. The pigments of the bile ; and, 3. The pigment of the urine.

1. THE COLOURING MATTER OF THE BLOOD.—The colouring matter or pigment of the blood has received various names, Hæmoglobin, Hæmato-crystallin, and Cruorin. The terms, hæmatin and hæmatoidin, are now restricted to those crystals which are produced by physiological agencies, in clots formed by the effusion of blood into the cavities or tissues of the body.

1. *Hæmato-crystallin, or Hæmoglobin* (Plate I. figs. 19, 20, 22), as already mentioned, is the most complex substance found in the body. It is represented, according to Thudicum, by the formula $C_{600}H_{960}N_{154}FeS_3O_{177}$. It may be obtained in a crystalline form by adding water, ether, chloroform, or alcohol, to a drop of blood on a slide of glass, covering it over with a thin covering glass, allowing it to stand for one or two hours, and then examining under the microscope. Lehmann obtained it by passing a slow stream of oxygen through a mixture of blood and water for fifteen minutes, then a stream of carbonic acid till the fluid becomes bright red, when the hæmato-crystallin, crystallises out. The form of the crystals varies in different animals—being prismatic in man and most mammalia, tetrahedrons in the rat, mouse, and guinea-pig (fig. 22), hexagon tablets in the squirrel, and rhombohedrons in the marmot. The crystals are made black by nitric acid, and decolorised by chlorine. Hæmato-crystallin contains,

as proximate constituents, an albuminous body, which is colourless; and hæmatin, which is coloured, and retains the iron of the original substance. According to Hoppe-Seyler* and Stokes,† hæmato-crystallin exists in the blood in two forms, the one called *hæmoglobin* (Hoppe-Seyler) or purple cruorin (Stokes), the other *oxy-haemoglobin* (Hoppe-Seyler) or scarlet cruorin (Stokes), differing from the first in having a certain amount of oxygen in loose combination. The spectroscope affords the only means of distinguishing between these modifications. When a thin layer of arterial blood mixed with water is examined by the spectroscope, two dark and sharply defined absorption bands are seen between D and E, one close to D, the other and thicker one close to E; if D is at 80 of the scale, and E at 106, the first band runs from 81 to 87, the other from 95 to 106. This is the spectrum of oxy-hæmoglobin. But if the solution is treated with any reducing agent, depriving it of its oxygen, such as ferrous sulphate, it assumes a purple colour; and when again examined, it will be found that the two absorption bands have disappeared, and only one band, stretching from 82 to 97, is to be seen. This is the spectrum of hæmoglobin. Since ordinary venous blood always contains some oxygen, the spectrum usually seen, of course, is that of oxy-hæmoglobin (two bands); but the blood of an animal dying of asphyxia, in which there is no oxygen, always shews the single absorption band of hæmoglobin (Hoppe-Seyler).

2. *Hæmatin or Hæmatoidin*—$C_{14}H_{18}N_2O_3Fe$ (Plate I. fig. 21)—is a crystalline substance often found in extravasated blood. It is produced by the decomposition of hæmatocrystallin into an albuminous body and hæmatin. It is sometimes amorphous in little grains or globules, sometimes in small crystals belonging to the monoclinic system. It is transparent, strongly refracting, yellowish red or ruby red, insoluble in all ordinary reagents, except potash. Iron is always found in this substance.

2. The Colouring Matters of the Bile.—Five distinct pigments have been found in the bile of man and other mammalia, namely, Bilirubin, Biliphæin, Biliverdin, Bilifuscin, and Biliprasin. (Plate I. fig. 23.)

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* Hoppe-Seyler, *Virchow's Archiv.* xxxiii. 446, xxix. 223 and 597; *Med. Centralbl.* 1864, p. 817; Handbuch. Chem. Anal. 1870.

† Stokes, Proced. Royal Society, xiii. 355.

1. *Bilirubin.* $C_{16}H_{18}N_2O_3$.—This substance constitutes the chief pigment in the bile of man. It may be extracted from gall stones by chloroform. It consists, when obtained pure, of minute amorphous granules, of a pure red colour, like nitric oxide of mercury (Pl. I. fig. 23). When precipitated by alcohol, it shews minute yellow rhombic prisms. By oxidation with nitric acid, this substance is converted into biliverdine, giving a beautiful play of colours, first green, then blue, purple, violet, and, lastly, a dull red or brownish yellow, affording a test for very small quantities of bile in the urine.

2. *Biliphæin or Cholophæin.* $C_{16}H_{18}N_2O_3$ (?)—According to Dr Thudicum, this pigment is probably a modification of bilirubin, at least it is intimately related to it. It is obtained from gall stones, like bilirubin, by the solvent action of chloroform and alcohol, but at a later stage of the process. It is always crystalline, thus differing from bilirubin. The crystals have a dark, reddish brown colour, and belong to the rhombic system, being prisms with obtuse angles.

3. *Biliverdin.* $C_{16}H_{20}N_2O_5$.—Though found only in small quantity in the bile of man, it is the chief pigment in the bile of herbivorous animals. It is obtained by the oxidation of bilirubin. When bilirubin is dissolved in caustic potash and exposed to the air, it becomes gradually green. On addition of hydrochloric acid, biliverdin is thrown down in flakes. It is soluble in alcohol, giving a beautiful green solution. It cannot be retransformed by any known chemical process into bilirubin or biliphæin. Dr Thudicum has devised a new test for this substance. On boiling an alcoholic solution of biliverdin with caustic ammonia and silver nitrate, a reduction of the dissolved silver oxide is observed. On the addition of a mineral acid, a splendid purple colour is produced, due to the formation, by oxidation, of a new compound, termed bilipurpurin.

4. *Bilifuscin* ($C_{16}H_{20}N_2O_4$) and 5. *Biliprasin* ($C_{16}H_{22}N_2O_6$) have both been found to a very small amount in human gall stones by Staedeler. They are black, glossy, brittle, non-crystalline substances. An alcoholic solution of bilifuscin is of a light brown colour, while that of biliprasin is green. They are not of much importance to the physiologist.

Spectrum analysis has not yet afforded any definite results as regards the bile pigments. The spectrum of biliverdin shews a very brilliant red.

3. THE COLOURING MATTERS OF THE URINE.—Although large quantities of urine have been carefully analysed by various eminent physiological chemists, the state of knowledge regarding the pigments is very indefinite. It is probable that in human urine three pigments exist, namely, urohæmatin (Harley), urochrome (Thudicum), and uroxanthin (Heller), or Indican (Schunk).

1. *Urohæmatin.*—This substance is a dark red amorphous mass, resinous in consistence, containing iron, readily soluble in ether, alcohol, alkalies, and fresh urine, but insoluble in water and acids. Harley—who isolated this substance by a very complex process, which it would be out of the province of this work to describe—regards all the other pigments discovered by other chemists as derivatives of urohæmatin.

2. *Urochrome.*—Dr Thudicum extracted from a large amount of urine, an amorphous, yellowish substance, easily soluble in water and acids, less so in ether, and least of all in alcohol (thus differing in a marked degree from Harley's urohæmatin), to which he gave the name of urochrome. According to this chemist, urochrome yields, by decomposition, a purplish-black matter, insoluble in water, and very slightly soluble in alcohol, called *uromelanin.* Uromelanin does not exist, as such, in the urine, but is derived from urochrome. The urochrome, however, does not immediately yield uromelanin, but a less oxidised substance, of a light yellow colour, which, however, becomes brown on exposure to air, and in course of time is precipitated as a perfectly black pigment. The composition of this black pigment is $C_{36}H_{43}N_7O_{10}$, very similar to that of the black pigment (melanin) found in the choroid of the eye, and in melanotic cancers. Taking into consideration the very high atomic weight of this substance (733), Dr Thudicum believes that it may possibly be derived from hæmato-crystallin, the crystallisable compound of the blood corpuscles, which, as already explained (p. 32), may be split into an albuminous body, and into hæmatin. According to this view, uromelanin would be a derivative of hæmato-crystallin, as uric acid is a derivative of albumin.

3. *Uroxanthin or Indican.* $C_{26}H_{31}NO_{17}$.—This substance occurs in human urine, both healthy and diseased; and when present in considerable quantity, causes the urine, after spontaneous fermentation, or on addition of acids, to deposit sometimes indigo-blue (uroglaucin of Heller) or indigo-red (urorhodin of Heller). It may be detected by precipitating the urine with

basic acetate of lead, collecting the precipitate which forms in the filtrate on addition of ammonia, and decomposing it with cold dilute acids ; the filtrate then depositing, first, indigo-blue, then indigo-red, and afterwards other products of the decomposition of indican. Thudicum, however, denies the presence of indican in the urine.

The chemical constitution of the various tissues, such as muscle, nerve, tooth, bone, &c., the analyses of the different fluids, secretions, and excretions, such as the blood, bile, saliva, gastric juice, urine, fœces, &c., and the chemistry of the great functions, such as digestion, respiration, nutrition, &c., will be hereafter described.

GENERAL HISTOLOGY.

The ultimate elements of the tissues have been variously classified. We shall consider them under four heads : 1st, the molecular ; 2d, the cellular ; 3d, the fibrous ; and 4th, the tubular elements of the tissues,—concluding with a consideration of the general doctrines of their origin and development.

The Molecular Elements of the Tissues.

Definition.—By a histological *molecule* is to be understood a minute body, seen under high magnifying powers in all organic fluids and textures, varying in size from the four thousandth of an inch down to a scarcely visible point, which may be calculated at less than the twenty thousandth of an inch in diameter. Optically it is distinguished according to its size ; the smallest presenting dark or light points as the focus is changed, and the larger exhibiting a dark or light centre, surrounded by a distinctly shadowed ring. These last are frequently distinguished by the name of *granules.* The ultimate molecule has never been reached, even with the highest magnifying powers. In the same manner that the astronomer with his telescope resolves nebulæ into clusters of stars, and sees other nebulæ beyond them, so the histologist with his microscope magnifies molecules into granules, and sees further molecules come into view.

The chemical composition of molecules must vary infinitely, but I have been in the habit of classifying them into four groups, and referring them to—1st, the albuminous; 2d, the fatty; 3d, the mineral; and 4th, the pigmentary compounds. These component constituents may be mingled together in various proportions, so as to produce simple and compound molecules.

Physical properties.—In the vast majority of cases they are globular in shape, but they may be angular, square, and of various forms. They may differ in size, or be of tolerably uniform size in the same liquid or substance. They may be regularly or irregularly diffused in the matter examined. Sometimes they are concentrated in particular places, and at others scattered in groups (Pl. II. *a*, *b*, *c*, *d*). Their colour is various. Most of the pigments in plants and animals are dependent on the formation of molecules, which in the human lung have been proved to be pure carbon; and in the tissues of plants and animals, differently tinted kinds of fat or of wax.

Development of molecules.—Molecules may be formed in two different ways—1st, by precipitation in fluids or semi-solid substances; 2d, by the disintegration of previously formed tissues. The former may be called *histogenetic* (ἱστος and γενος), and the latter *histolytic* (ἱστος and λυοις—dissolutio)—a term first proposed by Dr Lyons, of Dublin. They may be also denominated molecules of formation and molecules of disintegration.

Histogenetic molecules are formed either from the union of two simple organic fluids, or from precipitation occurring in formative fluids holding various substances in solution. It was Dr Ascherson, of Berlin, who first discovered, in 1840, the important fact that the mere contact of oil and fluid albumin caused the latter to coagulate in the form of a membrane, which he called the haptogen membrane, from ἁπτωμαι, to come in contact. A more complete mixture of two such drops produces, as is well known, a white opaque fluid or emulsion, which structurally exactly resembles milk—that is to say, it consists of molecules composed of a drop of oil surrounded by a layer or membrane of coagulated albumin. Such compound molecules possessing the property of endosmose may therefore readily be produced artificially, and by trituration can be reduced in size, so as to resemble the elementary molecules in chyle or in the yolk of the egg. If oil and albumin be introduced into the stomach and intestinal canal, they are always so reduced; and one of the objects of digestion would appear to be, separating from the food and rendering fluid its oil and albumin, so as to produce the chyle molecules, which are ultimately transformed into blood. Indeed, everywhere in living organisms it may be observed that oil and albumin, formed as secretions by plants, and entering the bodies of animals as food, either separately or united, constitute the chief origin of molecular formations.

Mr Rainey pointed out the condition which causes molecular mineral matter to assume the form of rounded nuclear bodies.* This condition is viscosity. If carbonate of lime be dissolved in water, the forms produced on its precipitation are crystalline, but if the the fluid be glutinous—composed, for example, of fluid gelatin or gum—the forms produced are oval or globular. Precipitations made in this way on slides of glass, closely resemble the appearances called nuclear or cellular in different stages of development, as in Pl. II. fig. 3. By allowing a drop of the watery and a drop of the gummy solution of carbonate of lime to come in contact, it may be shewn how the crystalline gradually passes into the rounded nuclear forms (Pl. II. fig. 4.) Mr Rainey has further shewn how starch granules are produced in the juices of vegetables, by the endosmose of gum into a cell containing a solution of dextrin.† In the same manner that the contact of oil and albumin produces oleo-albuminous molecules, so does the contact of gum and dextrin precipitate starch molecules. In this manner we can comprehend how the mixture of various organic fluids gives rises to particles of different kinds.

Histolytic molecules are the result of the transformation and disintegration of fluid and solid substances, by chemical or mechanical action. They are often larger in size than histogenetic molecules, are more purely fatty, and from being sometimes associated with the *dêbris* of broken-down texture, may, in such cases, be readily distinguished (Plate II. fig. 1, *d*). Thus, in the breaking up of cells or of muscle, when they become fatty, or in the putrefaction of animal or vegetable matters, these may be seen to soften, lose their peculiar structure, break up, and ultimately be reduced to a molecular condition.

We shall subsequently see that these two kinds of molecules are constantly changing places ; or, in other words, molecular matter formed from the process of disintegration, may, when placed under peculiar circumstances, become the basis of matter which undergoes development. In nature, the breaking down of one substance is the necessary step to the formation of another, and the histolytic or disintegrative molecules of one period become the histogenetic or formative molecules of another. This fact constitutes the basis of the law, which I shall subsequently seek to establish.

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* On the Mode of Formation of Shells of Animals, of Bone, and of several other Structures, by a process of Molecular Coalescence, &c. By Geo. Rainey, M.R.C.S. London, 1858.

† Microscopical Journal, 1858.

That histolytic molecules are capable of arranging themselves into all forms, admits of demonstration. In an old preparation of areolar tissue, mounted in spirit, in my possession, innumerable fatty molecules have been precipitated on the glass, which have arranged themselves as represented (Plate II. fig. 2). In other molecular masses in the same preparation, round spaces or vacuoles have formed themselves. I have seen exactly the same arrangement and structure in the earliest formative stage of vegetable mould.

Molecular movements.—These molecules are governed by forces which induce among them a variety of movements, and cause them to combine in definite ways. This force, which we may call *molecular force*, is altogether independent of cell, nucleus or other form of structure.

1. There are the molecular movements described by Robert Brown—hence called *Brunonian* movements. These vibratile, circular, serpentine, or irregular motions, may be observed whenever molecules are suspended in fluids of certain densities, but are too well known to require notice here. They occur altogether independent of organised structures, and must be regarded as in their nature purely physical.

2. The peculiar movements observed in the interior of cells, vegetable or animal. Amongst these I may refer to those seen in the large vegetable cells of the *Chara*, *Vallisneria*, and *Tradescantia* amongst plants, and those of chyle, the yolk of the egg, and of the salivary cell amongst animals. It has been much disputed whether this class of molecular motions be physical or vital.

3. I have frequently watched the formation of vibriones in putrid fluids. A scum, composed of molecules, collects on the surface : gradually several of them unite in minute filaments, more or less long, which assume vibratile or serpentine movements, and move in various directions across the field of the microscope. Such movements must be vital.

4. Other movements, which are unquestionably vital, occur

in the molecules of the yelk, on the entrance into the ovum of the spermatozoid. Here it cannot be maintained that the results are purely physical, because in different ova we see such widely varying effects from apparently the same cause. Neither can it be attributed to any direct influence of the cell, or of its nucleus—the germinal vesicle. For example, an egg is fully maturated in the female organs of generation, and would prove abortive if a spermatozoid did not find its way through the zona-pellucida, and get amongst the molecules of the yolk. As soon as it does so, the apparently purposeless Brunonian movements receive a new impulse and direction. Both spermatozoid and germinal vesicle are dissolved among them, and that wonderful phenomenon of the division of the yelk takes place, not by cleavage or other action of the cell-wall or nucleus, but by the separation of the mass into two masses instead of one. The nature of the phenomenon in this case may be compared to what is observable in a dense crowd of men called upon to pass over to the right or left hand in order to settle any disputed question by a majority. At first unusual confusion is communicated to the whole ; some hurry in one direction, others in another ; but after a time there is seen at the margins, where the crowd is least dense, a clear space, which gradually approaches the centre, and at length bisecting the whole, produces a complete segregation of the crowd into two portions. So with the molecules of the yelk in the egg after impregnation : their movements are directed by conditions which did not previously exist, and a stimulus is imparted to them which causes the peculiar result. It is the division and sub-division of the yelk, wholly or in part, which produces the germinal mass out of which the embryo is formed, and this not by any direct influence of the cell or nucleus, but in consequence of a power inherent in the molecules themselves, which was communicated to them for a specific purpose.

5. The peculiar movements so well described by Brücke, Von Wittich, Harless, and especially by Mr Lister, in the pigment cells of the frog's skin,* and which occasion the sudden change of colour in the chameleon, in fishes, and numerous other animals. The black pigment molecules may be diffused throughout the cell or concentrated in a mass, and all kinds of

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* On the Cutaneous Pigmentary System of the Frog.—*Philosophical Transactions*, 1858.

intermediate gradations may exist between diffusion and concentration. The change in colour is owing to these alterations in the molecules, the tint being light when they are concentrated, and dark when they are diffused. Mr Lister ascertained by experiment that their concentration is caused by exposure to light, by death of the animal, and by sudden section of the nerve going to the skin ; while darkness and irritation of the nerve or skin cause diffusion. Sudden amputation of a limb produced at first diffusion, followed by the concentration of death. These movements of the pigment molecules are peculiarly vital, and altogether independent of the cell-wall or nucleus. The former is stationary, and acts only as a sac or investing membrane around the moving particles, while the concentration of them about the nucleus is purely accidental, and frequently occurs in other parts of the cell. I have seen these molecules myself, as Mr Lister describes them, streaming out to and returning from the circumference under the influence of the stimuli referred to, where no cell nor nuclear action could be thought of (Plate II. figs. 13 to 16).

6. There are many other kinds of movements which are evidently unconnected with cells : for example, the contractile fibrillæ of muscle are not dependent for their inherent power on cells or other form of structure, but on the square-shaped molecules of which its substance is composed (Plate IV. figs. 24, 25). The same may be said of the movements observed in the amæba, in pus, mucous and colourless blood cells, as well as in other viscous masses, and which are now generally denominated *amœbiform.*

All these phenomena are connected with the molecules themselves ; the force occasioning them is a molecular force, and has nothing to do with pre-existing cells, or supposed germinal centres, as some have imagined. Further, there can be no doubt that some of these actions are in their nature purely physical, whilst others are peculiar to living beings, and therefore vital. We have, therefore, to determine, if possible, what are the physical and what are the vital laws of molecular coalescence and disintegration.

Physical law of molecular coalescence and disintegration.—The power of combination between two molecules, which, under peculiar conditions, not only move, but so move as to advance towards and press upon each other, that they at length unite and produce higher forms, must be attributed to a molecular force, operating in obedience to fixed laws. Thus it was demonstrated by Newton, that in a sphere the total attraction resulting from the particular attraction of all its component parts, is, as regards any body drawn towards it, the same as if they had been concentrated at the centre. Hence minute spherical particles, as so many gravitating points, will be drawn towards each other with a force varying inversely as the squares of the distances between their respective centres. Molecules, therefore, occurring in a fluid medium of equal density, or nearly so, will, by their mutual attraction alone, form themselves into spherical collections or masses. But when two spherules unite to form a larger one, they must each first disintegrate. In other words, they must both fall into pieces, and afterwards be put together under the same static conditions as they were before (Plate II. fig. 17).

When bodies assume the dumb-bell or elliptical form, perfect coalescence of two globules has not taken place. Under these circumstances, the molecules, in a mass contained in the inner hemispheres, coming within the attractive influence of both spherules, are simultaneously drawn in the direction of their centres by two variable forces, whose sum is always a constant quantity, as shewn in the diagram (Plate II. fig. 19). Here the axis major is A B, and the axis minor C D. The foci are the points c and c' which are the centres of the coalescing spherules, and the co-ordinates of the curve over the lines $c\,p$ and $c'\,p$. The coalescence of two such spherules will cause the dumb-bell shape gradually to disappear, and the spherical form of the remote hemispheres to be changed into that of an ellipse, so that at length the exterior outline also becomes elliptical, and there results a form presenting two ellipses, one situated within the other (Plate II. fig. 3, *a*). The still further coalescence of two sphericle particles, would end in two perfect spheres, one inside the other (fig. 3, *b*).

The appearance of a nucleus in these bodies is owing to their possessing different degrees of density. In fact, formed as they are under the influence of gravity, their density varies according to the degree of attraction exerted upon their particles, —an attraction which is as their distance from the centre,—the force being least at the centre, and greatest at the circumference. Hence, when looking at it by transmitted light, the object appears flat with a nucleus. The concentric lamination in the larger concretions is owing to another cause, viz., the union of successive masses, as in Pl. II. fig. 3, *b*. and fig. 5. All three stages in the formation of these bodies, namely, the collecting of the spherical particles into globular masses, the disintegration of these particles, and the final arrangement of their molecules in a laminated form, are all the effects of the same cause,—universal attraction or gravity. They are seen not only in the microscopical bodies, which have been so commonly regarded as cells, but in urinary, biliary, and intestinal calculi.

When crystalline are converted into globular forms, as in the ingenious experiments of Mr Rainey, who mixed a watery with a viscous solution of an earthy salt, he supposes that the two equal molecular masses, instead of attracting, repel each other. They will then arrange themselves in a spherical form, of which the central molecule will retain its position, whilst those around it will be thrown into diverging lines or radii going from the centre. Two such groups, if now placed side by side, will have their adjacent molecules impelled in directions which intersect one another (see Pl. II. fig. 18). The point of intersection at *a* and *a'* will denote the amount of the attraction of gravitation necessary to balance the force of impulsion acting on the molecules at *a*, and so bring them into the condition of rest. A quadrilateral figure would in this way be produced, or a primitive crystal, and the shape of such crystal would vary according to the density of the fluid, the relative size of the masses, and other causes influencing the amount of attraction, at *a*, *a'*, and so varying the angle, A C B, thus forming different angular primitive crystals. Thus the straight radiating fibres from the centre to the circumference in any particular body, are in their nature crystalline, while the concentric circles are not so. Hence attracting and repellent properties may exist in one body. The whole also may be modified by chemical and electrical actions, as well as by heat, which would occupy too much space to consider here. It is sufficient for us to know that physical forces may, under different circumstances, produce crystals from limpid, and globular nucleated bodies from viscous fluids, and that the latter closely resemble those forms which have been generally considered as organic.*

It results from these observations of Mr Rainey, and from his careful investigations into the structure of shells, especially those of the lobster, crab, oyster, &c., that many forms and processes, hitherto considered as altogether owing to vitality in the tissues of plants and animals, are the result of purely physical operations. The physical law of molecular disintegration also has been made out by Mr Rainey, who shews, 1st, That spherical bodies, formed on the principle of universal attraction, in a medium of given density, become in one of greater density gradually disintegrated, and that these molecules, at first completely separated, afterwards re-arrange themselves in fresh forms. Thus the nucleated bodies (Pl. II. fig. 3) soon lose their shape when kept in glycerin, and leave a membranous organic looking structure behind of the inspissated gum. 2d. The addition of acids or chemical combinations produce similar effects. 3d. The same results occur if, when the artificial calculi are well formed, they are put into a glass well filled with the solution taken from the same bottle, and so secured from the access of air that no alteration in its density or chemical composition can take place. This last is a most important fact, shewing that the same physical power which leads to the formation of these artificial bodies, when long continued, leads to their disintegration or destruction. These changes occur slowly, and require time, but their contemplation, when regarded as purely physical phenomena, must strike us with surprise as being closely allied to our conceptions of the progress of life itself.

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* Op Cit. pp. 81-83 and 99.

Mr Bridgman of Norwich has shewn that bodies produced slowly by Mr Rainey's process, may be formed in a few hours by inserting into viscous solutions of carbonate of lime the two wires of a galvanic battery; and he further concludes from experiments, that molecular precipitation is influenced by electrical currents, so that if a tissue be in a negative state it grows, and if in a positive state it disintegrates. "To set up absorption, therefore," he says, "it is only necessary to induce an electro-positive condition of a part." Further, he has succeeded in forming artificial cartilage and bone by placing dentine in albumin or white of egg, and inserting the wires of a galvanic battery. He says:—"Around the negative pole will be found a large mass of brilliantly clear and transparent jelly. This substance, although it has been formed out of albumin only, is entirely altered in its character. It is no longer, like albumin, soluble in cold water, or coagulable by heat. It has become identical with the material of basement membrane and bone cartilage. . . . The portion formed at right angles to the two poles is of this character in its densest state, almost, if not quite, equalling the densest cartilage. An examination by the microscope shews that it is also in some parts thickly studded with peculiar globular crystals of lime, closely resembling those figured by Mr Rainey. It is thus, in its composition, strictly analogous to bone in the early stage of its calcification."*

I have examined some of Mr Bridgman's preparations, and can confirm the accuracy of his descriptions. In the section of a young horse's tooth, these nucleated bodies may be seen at the margin of the crusta petrosa, uniting with its substance to form bone (Pl. V. fig. 12). When, moreover, we compare the concentric rings and laminæ surrounding the Haversian canals, with the like arrangement existing in calculi and all concretions, there can be little doubt that the mineral deposits in bone are, in no small degree, connected with the molecular law of aggregation. Many years ago I discovered that the pellicle which forms on the surface of lime-water presents the appearance represented (Pl. II. fig. 7), and closely resembles pavement epithelium. It is evidently caused by the nucleated calcareous concretions becoming flattened, and adhering at their edges, in the same manner that epidermic cells do.

Other facts of great importance have in recent years been discovered, having relation to the physical condition of viscous matter in the animal body. Of these may be mentioned—

1. The discovery by Graham of the facility with which saline limpid solutions pass through membranes, whereas those of gum, dextrin, gelatin, albuminous substances, &c., pass through with great difficulty, or not at all. The former he named crystalloids, the latter colloids.

2. The discovery by myself of the manner the numerous hyaline or diaphanous bodies, so common in morbid products, are produced.† A glutinous matter forms within the substance of cells, which, under certain conditions, may be squeezed out of them by pressure, giving rise to a multitude of globular transparent bodies, which float loose in the field of the microscope (Pl. II. fig. 11).

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* On the absorption of bone and dentine, p. 11.

† See "Journal of Anatomy and Physiology," vol. i. p. 322. 1867.

3d. The recent experiments of Montgomery with protagon, or myelin,* a substance obtained by boiling yolk of egg with alcohol. On the addition of water, there may be seen shooting out from a mass of it under the microscope, processes which often assume a spiral form (Pl. II. fig. 8), or enlarge at their extremities to produce rounded knobs, having concentric circles (Pl. II. fig. 9). When broken down with water, albumin, glycerin, serum, or other substances, and acted upon by weak acetic or nitric acids, this substance can be made to assume the form of areolar and elastic fibres, spiral ducts, varicose nerve tubes, the broken up substance of brain and spinal cord, or nucleated cells—simple and compound, pus and cancer cells, and bodies, which, like the salivary corpuscles, exhibit numerous granules in their interior, possessing active molecular movements. (See Pl. III. fig. 29, *a b c d e.*) I have repeated these experiments of Dr Montgomery and annually shew to my practical classes the artificial cell, fibrous, and tubular forms which may be thus artificially produced. †

We see molecules, therefore, combining in the forms of crystals and nucleated spherules, and inasmuch as we have discovered the physical conditions on which they depend, and can produce them artificially, we have no difficulty in classifying these among purely physical phenomena, even when they occur in the interior of animals. But when other molecules unite to form nuclei cells, and fibres, and these arrange themselves into tissues and organs to produce plants and animals, we are ignorant of the conditions by which these results are brought about; we cannot imitate them artificially, and we are content to call them vital. That is to say, that certain actions originate in, and are directed by, conditions which are as yet undetermined, but which, as they only occur in organic, as distinguished from inorganic bodies, constitute vital activity. Not that an organized body is independent of physical forces, but that certain influences are communicated to them, which, as invariably resulting in specific forms or properties, make up the sum of what we call vitality. These also seem to be governed by a fixed law.

The vital law of molecular coalescence and disintegration.—In endeavouring to determine the nature of vital actions impressed upon molecular matter, I have been led to the following law or generalization, namely, THAT THE DEVELOPMENT AND GROWTH OF ORGANIC TISSUES, ARE OWING TO THE SUCCESSIVE FORMATION OF HISTOGENETIC AND HISTOLYTIC MOLECULES. We have already seen that development and growth in animals, originate in the molecules of the yelk of the egg, or of a germinal molecular mass, formed from organic matter. In either case it would appear that the first form is molecular; that the molecules unite to produce nuclei and cells; that these become disintegrated to produce a secondary mass of molecules; that these again unite to form secondary nuclei and cells, and that the same process is repeated more or less often in various developments, until the animal or tissue is formed. This constitutes the successive histogenetic and histolytic molecules, observable in the process of growth—the former building up to a certain extent, and the product disintegrating to produce the latter, which, after a time, again re-arrange themselves, and become histogenetic to form cells or tissues, which, in their turn, break down and become histolytic. We shall see, that not only development, but that growth and secretion, absorption and excretion, are only different names given to histogenetic and histolytic processes, and that these are brought about by formative and disintegrative molecules.

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* Montgomery on the formation of so-called cells. London. 8vo. 1867.

† See the author's note in the Trans. of the British Association. 1867.

No one can carefully watch the mode in which infusoria are developed, without being satisfied that they originate from the coalescence of molecules, and not from ova or spores, as has been imagined. On making a cold or hot infusion of any vegetable or animal substance, covering the vessel with a piece of paper, so as to exclude the dust, and then watching it every twelve hours, the first change visible to the eye is a slight opalescence, and the formation of a thin scum or pellicle that floats upon the surface. This appears at times, varying from a few hours to several days, according to the temperature of the atmosphere or the nature of the infusion. On examining the pellicle or film under high magnifying powers, it is seen to be composed of a mass of minute molecules, varying in size from the minutest visible point to that of one thirty-thousandth of an inch in diameter. These molecules are closely aggregated together, and must exist in incalculable numbers. (Pl. II. fig. 10, *a.*) They constitute the *primordial mucous layer* of Burdach, and the *proligerous pellicle* of Pouchet. The same pellicle, examined six hours later, shews the molecules to be somewhat enlarged, and these separated by the pressure of the upper glass are already seen here and there to be strongly adhering together in twos and fours, so as to form a little chain. Many twos, also, have apparently melted together, so as to form a short staff or filament—*bacterium.* (Pl. II. fig. 10, *b.*) Twelve hours after this, it may be seen that the grouping of the molecules in twos, threes, and fours, has become more general, and that several of these form new groups of eight lengthways. Many of them have melted together to produce longer bacteria. At the edges of the molecular mass, and in the fluid surrounding it, may now be seen a vibratile movement in the shorter bacteria, and a serpentine movement in the longer ones, whereby they are propelled forwards in the fluid—*vibrio.* (Pl. II. fig. 10, *c d.*) From the second or third to the fifth or seventh days, the vibrios are lengthened, evidently by apposition of groups of other molecules, to their ends. These unite together endways, to form a filament, which may extend a third or half, and in a few cases entirely across the field of the microscope. (Fig. 10, *e.*) After a time they may be seen motionless, evidently dead. This occurs at various periods. They now rapidly disintegrate, and thus a second molecular mass or pellicle is produced. In this, rounded masses may be seen to form, which strongly refract light not unlike pus corpuscles, or the colourless corpuscles of the blood. These soon begin to move with a jerking motion, dependent upon a vibratile cilium attached to one of their extremities—*Monas lens.* In a day or two other cilia are produced, the corpuscle enlarges, is nucleated, and swims through the fluid evenly. Varied forms may now occur in the molecular mass, dependent on the temperature, season of the year, exposure to sun-light, and nature of the infusion, all having independent movements. They have been denominated *Amœbœ*, *Paramecia*, *Vorticellœ*, *Kolpoda*, *Keronœ*, *Glaucoma*, *Trachelius*, *&c.* It is unnecessary to follow the development of all the forms that may arise. They originate always long after the primary vibrios are produced, in the secondary, tertiary, or even later molecular masses, resulting from the disintegration of previous forms. *

At other times, it happens that the molecular mass, instead of being transformed into animalcules, gives origin to minute fungi. In this case the molecules form small masses, which soon melt together to constitute a globular body, from which a process juts out on one side. These are *Torulæ*, which give off processes which are soon transformed into jointed tubes of various diameters, terminating in rows of sporules *(Penicillium)*, or capsules containing numerous globular seeds *(Aspergillus)*. Occasionally filaments are formed from the direct melting together of molecules, arranged longways *(Leptothrix)*. (See Pl. II. fig. 10, *f*). Why the molecules should sometimes arrange themselves in long rows, and at others into rounded masses, is probably dependent on varying degrees of limpidity and viscosity. But why both these forms of molecular matter should sometimes possess an inherent power of contractility, and at others not, it is impossible as yet even to surmise. But on the determination of this point, the variations existing between the different kinds of fermentation and putrefaction, are evidently dependent. In all these processes, varied forms, whether animal or vegetable, may be seen to arise in a clear fluid, from the coalescence of histogenetic and histolytic molecules, without ova or spores of pre-existing organisms.

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* See lecture on the Atmospheric Germ Theory and Origin of Infusoria, by the Author, *Monthly Journal of Medical Science*, March 1868.

The development of the *Ascaris mystax* offers another excellent example of the molecular law of organization. In describing it, I shall follow the observations of an independent accurate observer. The figures in Pl. VII., therefore, are copied from the original drawings of Dr Nelson, contained in his prize thesis, "On the Development of Entozoa," presented to the University of Edinburgh on his graduation, 1850. A portion of this thesis and some of the figures were subsequently published in the "Philosophical Transactions," vol. 142, for 1852. From the large number of drawings in the original memoir, it has been found necessary to make a selection, so that several of the intermediate changes have been omitted. A glance, however, at the series now given will, I trust, convey an accurate idea of what I understand by growth from successive histogenetic and histolytic molecules. Figs 1 to 3 represent the histogenetic changes which take place among the molecules deposited in the ovarian tube of the female worm, until the fully maturated ovum (Fig. 4) passes into the oviduct. Fig. 5 exhibits the contact with, and entrance of the spermatozoids into, the ovum. This act of impregnation is followed by breaking down or fusion together of the male and female elements (Fig. 6), and the formation of a chorion, the germinal vesicle being still visible

(Fig. 7). This also soon dissolves, and the interior of the ovum is now reduced to a mass of histolytic molecules, dense in the centre, but beginning to clear up at the circumference (Fig. 8). These now clear up still further, then meet together, concentrate themselves, and form histogenetic molecules, as seen in Figs. 9, 10, and 11 ; and a membrane forming round them (Fig. 11), another included cell is developed, as in Fig. 12). This divides itself into two (Figs. 13, 14). Each half separates into other two, as in Fig. 15, and the process of division is seen going on in Figs. 16, 17, 18, 19, and 20, until another histolytic mass of molecules is produced, as in Fig. 21. From this mass the perfect worm is formed directly by simple coalescence of the molecules, which again become histogenetic. They unite together, concentrate themselves, and separate from the vitelline membrane, Fig. 22. A cup-shaped depression then occurs (Fig. 23), which, passing through the mass, forms a ring (Fig. 24) that is seen to be divided at one place. The two ends of the ring now elongate and cross one another (Fig. 25), and the molecules go on coalescing to form the body of the worm. This next becomes spiral, as in Figs. 26 and 27, and on the breaking of the vitelline wall is extruded as the perfect animal (Fig. 28). During this process the molecules of the ovary first coalesce to form the ovum. After fecundation, the spermatozoids and germinal vesicle disintegrate and form histolytic molecules. The mass then re-arranges itself to produce an included cell, which, constantly dividing, is once more reduced to histolytic molecules. These by a third act of histogenetic coalescence produce the perfect animal.

In this and a vast number of similar observations, which will be subsequently referred to, it must be evident that a certain series of molecular transformations is necessary for the one which follows it. Thereby is produced a continual elaboration of matter—a constant chemical and morphological series of changes, the exact number and order of which in the production of organic forms only require time and perseverance to discover. Doubtless various conditions, dynamical, chemical, and vital, must co-operate in producing the result, and they must all influence molecular as well as every other kind of combination. Such considerations and facts must convince us of the error of endeavouring to place the source of special vital action in any particular form or arrangement of organic matter, whether fibre, cell, nucleus, or molecule. Each and all of these elements have their vital endowments, which re-operate on the others ; but inasmuch as the molecular element is the first as well as the last form which organised matter assumes, it must constitute the principal foundation of organisation itself.

THE CELL ELEMENTS OF THE TISSUES.

Definition.—By a cell is understood a microscopical object composed of an external envelope—the *cell wall* or membrane—containing an included body, which is called its *nucleus*, and having between the nucleus and cell wall a substance named the *protoplasm*, *cell sap*, or *cell contents*. These three constituents of the cell present great variation as to thickness, size, or bulk.*

Physical and chemical properties of cells.—The cell wall is more or less thick and resistant. In plants it is frequently double, the inner one having been denominated the *primordial utricle* by Von Mohl. Occasionally it is not separable from the protoplasm, nor can it always be shewn to exist as a distinct membrane. The nucleus is usually round or oval, is solid or hollow, homogeneous or molecular. It varies in size, and generally contains one or two included granules, called *nucleoli*. The contents may be fluid, gelatinous, or solid, and present the molecular, granular, fibrous, or crystalline forms.

These constituents of the cell are also for the most part of different chemical composition. The cell wall in animals is generally albuminous, and is partially soluble in acetic acid. In the inactive epidermic and cartilaginous cells, this change does not occur, as the cell walls in them are gradually converted into horn and chondrin. When actively performing their functions, the walls readily admit of endosmotic currents, swelling out on the addition of water, and collapsing when immersed in dense solutions. They may be rendered impervious from fatty or mineral degeneration, and thus lose their active properties. The nucleus is usually different in chemical composition from the cell wall, undergoing no change on the addition of acetic acid, and frequently becoming more dense, with a thickened outline, on the addition of that reagent. It seems to be more allied to the fatty than to the albuminous compounds. It exhibits a marked tendency to combine with pigments, a circumstance which has recently been taken advantage of in displaying the textures, by steeping them in a solution of carmine. The contents vary greatly in chemical composition in different cells. They may consist of the secretions formed in the numerous glands—may be watery, holding various substances in solution ; oily or fatty ; pigmentary, the various pigments being generally coloured fats, although, when black, it may be caused sometimes by melanin, at others by pure carbon ; albuminous and scleroginous, as in the cells of many plants ; and mineral, as in many cells of plants and animals.

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* In recent times, with a view of still retaining the cell, as the ultimate element of organisation, some have shewn that it may exist without an external wall (Max Schultze), and others demonstrate that a nucleus is not necessary (Brücke). But it must be evident that without these parts we have only to do with a molecular mass, and that the adoption of such notions is equivalent to an abandonment of the cell theory. If an elementary part has not the structure of a cell, as defined by the founders and supporters of the cell doctrine, it can only create confusion in histology to apply the expression erroneously.

Cells may vary greatly with regard to their size, form, and relation to each other. In size some of them are as small as the 3000th, and others as large as the 400th, of an inch in diameter. In form they may be round, oval, polygonal, cylindrical, caudate, fusiform, branched, stellate, &c., &c. They may be densely crowded together, or widely scattered, isolated or aggregated, united by connecting fibres or tubes, or separated by various kinds of substance, called *intercellular substance.*

Varieties of cells.—Cells may be divided into three classes:—1st. Normal isolated cells, which never proceed beyond the cell form. These are lymph and chyle corpuscules, blood, nerve or ganglionic, fat, pigment, and glandular, secreting cells. 2d. Cells of transition—that is, cells which, for different periods in their earlier stage of development, present all the characters and functions of cells, but the tendency of which is to be transformed, or so arranged as ultimately to constitute a tissue. Among these must be placed many embryonic cells and fibre, epithelial and cartilage cells. 3rd. Cells only found in morbid conditions of the tissues, such as plastic or pyoid, pus, granule, cancer and tubercle corpuscles. Many of those classified among cells are in truth only nuclei, such as the chyle and blood corpuscles of mammals, tubercle corpuscles, and the free nuclei found in certain cancroid growths, especially fibro-nucleated tumours. To avoid unnecessary divisions, I have thought it

that from this central cell all the other cells of its department derive their origin. It is the mother of all those within its own territory."*

3. *The theory of Huxley* (1853).—A homogeneous plasma first exists, in which spaces (*vacuoles*) are formed, and these contain the cell wall, contents, and nucleus. The walls of these spaces are called *periplast*, the nucleus *endoplast.* This last he considers comparatively an unimportant element. "The periplast, on the other hand, which has hitherto passed under the names of cell wall, contents, and intercellular substance, is the subject of all the most important metamorphic processes, whether morphological or chemical, in the animal and in the plant. By its differentiation every variety of tissue is produced; and this differentiation is the result, not of any metabolic action of the endoplast, which has frequently disappeared before the metamorphosis begins, but of intimate molecular changes in its substance, which take place under the guidance of the 'vis essentialis,' or, to use a strictly positive phrase, occur in a definite order, we know not why."†

While each of these theories has numerous facts in its support, no one of them is capable of embracing all the facts of organisation. Thus there are several tissues which have never been known to contain, or to originate from, cells, such as the sarcolemma, vitelline membrane, anterior and posterior layers of the cornea, and capsule of the crystalline lens. The blood corpuscles of mammals are not cells, but nuclei. The striated muscular fibre has been shewn by the researches of Savory, Lockhart Clarke, and Braidwood to be formed from the molecular mass outside the embryonic nuclei, while the mineral matter of bone is first deposited in the intercellular substance, outside and often at a distance from the cartilage cells. These facts are opposed to an exclusive cell theory, as they are also to a nuclear or germinal centre theory. It is true the originator of this last doctrine was obliged by them to extend the influence of his centre, externally over a certain distance or territory, whereby he hoped to embrace the actions which are carried on in the intercellular substance. But, as pointed out by the supporter of the third theory, the centre often disappears while development in the matter outside it is active. A study of the development of the skeleton proves that mineral matter is first deposited outside cells and their nuclei, and proceeds, not from, but towards them ; while the earthy matter often assumes forms that no known combination of cells can be supposed to produce. On the other hand, there can be no doubt that in many cases development does proceed from the centre, by proliferation both of the nucleus and of the cell ; so that the difficulties imposed upon us by each of these theories simply depend upon their exclusive character.

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* Goodsir's Anatomical and Pathological Observations, pp. 1 and 2.

† Brit. and For. Med.-Chir. Review, vol. xii. p. 306.

4. *The theory of the Author* (1855).—It was at the meeting of the British Association in Edinburgh (1850) that I pointed out to the Physiological sub-section the defects of the cell theory, as explanatory of the formation of various textures. In 1852 I read another paper on this subject to the Physiological Society of Edinburgh.* But it was at the Glasgow meeting of the British Association in 1855 I brought forward the molecular theory of organisation,† which may be shortly stated as follows:—The ultimate parts of the organisation are not cells nor nuclei, but the minute molecules from which these are formed. They possess independent physical and vital properties, which enable them to unite and arrange themselves so as to produce higher forms. Among these are nuclei, cells, fibres, and membranes, all of which may be produced directly from molecules. The development and growth of organic tissues is owing to the successive formation of histogenetic and histolytic molecules. The breaking down or solution of one substance is often the necessary step to the formation of another ; so that the histolytic or disintegrative molecules of one period become the histogenetic or formative molecules of another.‡

This theory unites the views of Schwann, Goodsir, and Huxley, and explains the otherwise irreconcilable ideas concerning development sometimes proceeding from the nucleus, at others from the cell, and at others from the intercellular substance. It is supported by all that is known of development, and more especially by the former accurate observations of Schwann, as well as by the recent researches of Rainey, Savory, Clarke, and Beale. The last physiologist, however, in addition to the facts he has described, has advanced the following theory :—

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* Edinburgh Monthly Journal, May 1852, p. 476.

† Report of the British Association for the Advancement of Science, 1855, p. 119.

‡ Proceedings of the Royal Society of Edinburgh, April 1. 1861.

The theory of Beale (1861).—Every living elementary part (a cell) is composed of matter in two states, one, living, active, formative ; the other, lifeless, passive, formed. The first he calls germinal matter, which corresponds generally to the nuclei of the tissues, but also to the entire colourless blood and pus cell. It alone selects pabulum, and has the power of re-arranging its elements so that the various materials characteristic of the different tissues, including cell wall, intercellular substance, and the secretions are formed. By its division and subdivision, the multiplication of cells is effected, nutrient matter or pabulum enters from without, permeates the formed material, and flows towards the germinal matter as to a centre. There it is animated by the existing living matter. The origin of new centres of living matter is always within pre-existing centres. Matters that have once lived pass outwards to constitute formed or inanimate substances, so that what was first formed is that which is most external, and at the greatest distance from the germinal matter.*

It will not be denied that in the living body organic matter, which enters it as food, was once alive, and when converted into what Dr Beale calls pabulum, and deposited in the body, is again capable of living, although in a different structural and chemical form. It must also be admitted that some organic parts may be more active than others, and portions of them are constantly dying and disappearing to give place to new ones. This constitutes what I have called histogenetic and histolytic changes. We can agree with Dr Beale, therefore, in considering generally that some parts in the organism are alive, whilst others are dying or dead. The action of his germinal matter and germinal centres differ little from what was described by Goodsir. But when it is maintained more specifically that the living parts are the germinal centres only, and that all the textures outside and between them are lifeless, that is dead, such a view is irreconcilable to what appears to be the most obvious physiological facts. According to this theory, for example, the intercellular matter of cartilage, the striated substance of muscle, and the greater portion of nerve are passive and lifeless, yet in the first occur those active changes whereby cartilage is transformed into bone; in the second, those active contractions which produce motion; and in the third, that active sensibility which generates and transmits an influence when excited by various stimuli. All these, we maintain, are essentially vital actions, which can never appropriately be referred to dead substance.

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* On the Structure of the Simple Tissues, 8vo. London. 1861. See also "On Protoplasm," 12mo. London. 1870.

The recent modification of the molecular theory by Huxley, who supposes that all protoplasms are the same, and capable of being converted, as such, into one another, is opposed to observation. What we have pointed out, and shall subsequently further demonstrate is, that nutrition is dependent upon a series of histogenetic and histolytic changes of the protoplasm or molecular basis, without which development and function cannot be performed.

Reproduction of cells.—Cells once formed may propagate themselves in four ways:—(1.) *Endogenously*—cell may arise within cell; (2.) *Exogenously*—the included contents, molecular or nuclear, may be extruded from the cell, and form cells outside it; (3.) *Fissiparously*—the cell itself may divide, and separate to produce new cells; and (4.) *Gemmiferously*—a bud or small process may be given off from the cell wall, which may separate and be developed into a new cell. All these modes of cell reproduction may often be seen proceeding together in one plant; but in animals the first two are the most common in the adult, and the third in the embryo. In either case, the transformations may be traced to the active properties of their molecular constituents. Inside a cell, molecules may be precipitated, as well as outside, and there become obedient to physical and vital conditions, whereby they sometimes produce crystals and inorganic masses, at others nuclei, included cells, and other organic products.

Functions of cells.—Various cells possess different vital endowments. Whilst some, like the blood corpuscles, remain isolated, and assist in elaborating the fluid in which they remain, others are gradually transformed into the different tissues of the body, in order to give it support, ductility, and firmness. A third kind are busily occupied in secreting fluids, emptying them into reservoirs, and conducting matters which would be injurious out of the economy. Thus they are the organs of secretion and excretion. A fourth class either store up pigment, which gives colour to the textures, or accumulate pure oil or wax for important chemical or other purposes. A fifth class are endowed with contractility. So long as all these cell processes go on harmoniously, health is preserved. But sometimes a diseased condition is set up by an excess or diminution of one kind or another. The blood cells may be too many or too few. Glandular, epithelial, fibrous, cartilaginous or osseous growths may form from their local increase. Unusual colorations may be given to the textures, or obesity occasioned, by multiplication of pigment cells in the one case, and adipose cells in the other. Not unfrequently a material is poured out from the blood in a fluid state, which coagulates in a molecular mass, and then a new set of cells, such as pus cells, spring up in it, which break it down once again into a pulpy or diffluent mass, and at length by their own disintegration, allow the whole to be absorbed. Or, as in the case of cancer cells, these new formations, by possessing independent power of development, give origin to uncontrollable local and general growths of a fatal character.

These various endowments constitute the peculiar vital properties of cells, and prove that each must possess powers of attraction and selection. By attraction it draws from the neighbouring blastema the material necessary for its own growth and sustenance, which it converts, by a subtle chemistry of its own, into a variety of products. By selection, one cell appropriates this matter, and another that—often rejecting the substance that is greedily seized upon by its neighbour. In the higher animals, the nutritive blood appears to be the same in different organs; and yet we see cells, apparently similar in structure and chemical composition, forming from that blood a viscous saliva, an acid gastric, or an alkaline pancreatic juice. They also possess physical properties which are essential to the vital ones, among which must be classed the power of endosmose and exosmose, and the chemical differences previously pointed out to exist between nucleus, contents, and cell wall.

Cell movements.—In the same way that molecules have movements peculiar to themselves, so in certain cases have the other constituents of the cell, such as the nucleus, protoplasm, and cell wall. The embryonic heart of the chick may often be seen to be composed of cells, each of which, by its contractile movements, appears to give the organ its power of propulsion. Infusorial animalcules, consisting of nucleated cells, slowly or quickly dilate and contract their cell walls. The fibre cells scattered through the adult tissues do the same. In the stalks of *Vorti-*

cellæ is a spiral filament, formed from the nucleus, having contractile power, as have the filaments of spermatozoids, developed within cells. The walls of cells, again, have frequently hair-like processes attached to them externally, which are in constant movement, and are termed "cilia."

Conditions necessary for cell life.—The development of cells is dependent on certain conditions, which, so far as we are acquainted with them, appear to be as follows :—(1.) They must bear a certain relation to a nutritive fluid or *blastema*, from which they can attract and select the various substances necessary to enable them to carry on their respective functions. The most active growing cells are those that swim in such a fluid. In the higher plants and animals, the nutritive fluid (sap or blood) is distributed throughout the economy in a series of canals. (2.) A certain temperature is necessary to cell life, as it will not continue below zero or above 145° Fahr. As a general rule, a low temperature checks, while an elevated one is favourable to cell growth. (3.) Room for expansion is necessary to perfect cell formation. They grow most rapidly, and are best formed in fluids or very moist substances. When they begin to press upon one another, or upon unyielding tissues, their development is checked or destroyed. (4.) An appropriate locality has evidently a great influence over cell formation, and this independent of mere temperature and the other circumstances referred to. This is well observed, not only in nature generally, but in the reproduction of tissues in man ; the new matter originating the cells being in most cases the same, but more or less governed, in respect of the ultimate development, by the neighbouring structures. Lastly : The physical condition of the cell itself governs its development. If the cell wall becomes infiltrated with mineral matter, liquids do not readily pass through it ; if the cell fluid becomes loaded with albuminous, fatty, or mineral substances, or if the nucleus disappear, the growth and function of the cell are destroyed. The conjoined integrity of cell wall, contents, and nucleus, seems to be necessary for cell life, as each of these operates on the others, and on the surrounding blastema by endosmose and exosmose. Cells, therefore, are not absolutely the simple elementary parts which some consider them to be, but complex structures, in which at least three distinct substances enter to make the whole. Compared with molecules, they are a higher stage of existence, and essentially connected with the most important vital processes of the economy, such as nutrition, secretion, and reproduction. Conjoined with other elements of the textures, they are also essential to locomotion, sensation, and mental acts. Each individual cell, like every molecule, is endowed with a distinct life of its own, but of a more complex character. It is born, grows, arrives at maturity, declines, and dies. Many cells may even reproduce their own species, while others, by further development, are transformed into still higher forms of tissue. Hence our notions of life in general, as seen in the compound organism of a tree or a man, must always have reference to the multitude of minute molecules and cells, the united lives of which make up its own.

Perhaps nothing has more tended to revolutionise medical practice in recent times than the establishment of the cell theory. We observe that most of the great functions of the economy are carried on through the agency of cells, and that even pathological states are entirely owing to their existence, development, and degeneration. Thus pus—that fluid which surgeons formerly considered as a deposit or secretion foreign to the frame, irritating in its nature, and which therefore ought to be let out of the body as soon as possible—is, like the blood, a bland living fluid, crowded with multitudes of compound animal existences, which are born, live, and die as man himself does. That dreaded disease, cancer, owes its so called malignancy solely to the power of endogenous reproduction possessed by its cells ; while all alterations of texture, of nutrition, of secretion, and of development are, in truth, connected with their history. The conditions or laws which regulate cell life therefore become of immediate practical importance to the physician and surgeon. Thus the growth of cells is influenced by the same circumstances as influence growth in general. Cold and heat have long been recognised as the most powerful means of checking or hurrying forward the evolution of young plants and animals. This is the explanation of the effects of these agents on the products of inflammation. Does the surgeon wish to prevent suppuration—he applies cold lotions or ice ; if he wishes to favour it, he applies warm poultices. In the same manner as the horticulturist, when he desires to force fruit, places the plant in a hothouse, and supplies water,—so does the surgeon surround his indurated abscess with a local hotbed of heat and moisture. So likewise, the influence of compresses and pressure in restraining or retarding growth finds its explanation in the necessity all rapidly growing parts experience for room to expand in. We have previously seen that, inasmuch as cells are dependent on the existence of a molecular blastema, so the composition of this, as influenced by food and drugs, must point to a modification of cell function. But, above all, the vitality of these minute structural elements being inherent in themselves, must convince medical men that the morbid changes which they originate are extra-vascular, and thus induce them to look beyond that former common explanation of disease—namely, the so-called " action of the vessels "—for an explanation of pathological phenomena. Hence the conviction of the inutility of bloodletting and other remedies, which used to be so popular.

The varieties of cells have been previously referred to, we have now to describe the special characters and functions of each.

Chyle and Lymph Corpuscles.—*Chyle* differs from lymph in possessing a molecular basis, discovered by Gulliver, consisting of minute particles, varying in size from a point barely visible to the 1·20,000th of an inch in diameter. They are the result of the primary digestion, and are composed of oil surrounded by a layer of albumin. They strongly refract light, and are soluble in an excess of ether. Floating amongst these we observe granular and globular bodies about the 1·4000th of an inch in diameter, which, on the addition of acetic acid, exhibit a thicker margin than they did before. In chyle taken from the thoracic duct there are also bi-concave flattened disks, exactly resembling the coloured blood corpuscles in size and form, but destitute of colour. Between these two kinds of corpuscles all kinds of intermediate changes may be observed, so that there can be little doubt that the former become flattened, and are changed into the latter. They are in fact embryo blood corpuscles, which become coloured in the lungs. (See Sanguification).

Lymph is a transparent fluid, which contains a few molecules and cells, the latter varying in size from the 2000th to the 1000th of an inch in diameter. They are globular in shape, of molecular aspect, having a distinct cell wall and nucleus. On the addition of water they are enlarged by endosmose, while acetic acid dissolves the cell wall, and exhibits the nucleus as a single, double, or tripartite granular body. Occasionally it is oval, elongated, bent, and crescentic. These bodies are identical with the colourless cells of the blood, and may be seen in that fluid and in the chyle, mingled in varying numbers with other corpuscles and molecules (See Pl. III. figs. 1, 2, and 14).

Blood Corpuscles.—Three kinds of corpuscles exist in the blood—1st, a few molecules, which are those of the chyle, and are generally increased in number during active digestion. 2d, colourless cells, which are identical with those of lymph just noticed; and 3d, coloured corpuscles, which are the essential elements of the sanguigenous fluid. These last require special notice here.

Shape.—In man and mammals generally, the form of the coloured blood corpuscles is that of a bi-concave circular disk (Pl. III. fig. 3). Examined by transmitted light, the circular margin and shadowed spot in the centre is dark or light according to the focal point in which it is viewed. Seen edgeways, it presents either a straight line or a slight double concavity on each side. They have a great tendency to turn on their side and form rouleaux (Pl. III. fig. 3 and 13). Their shape undergoes rapid alteration on the occurrence of evaporation, when the blood is exposed to the air, the margins becoming irregular, crenated, serrated, or beaded (Pl. III. fig. 4). The same occurs after the addition of various re-agents as will be seen further on. In the *Camelidæ*, as was first shewn by Mandl, the corpuscles are oval, not flattened, and, like the bi-concave circular disks, contain no included body. In birds, reptiles, and fish, the corpuscles are oval (Pl. III. fig. 6, *a*, *b*, *c*, *e*, *f*). The oval varying in the bird, salamander, and frog. These corpuscles are distinctly nucleated, and are, therefore, cells. In the invertebrata, the shape varies much, being globular, oval, or fusiform (Pl. III. fig. 6, *h*). They may be also cellular, nuclear, or molecular.

When examined by a good oblique direct light on a black ground, Dr J. W. Freer of Chicago, shewed me that the coloured blood corpuscles of man and of the frog exhibited a prominence in the centre, as shewn (Plate III. fig. 12).*

Colour.—The colour of the blood corpuscles, as seen under the microscope, is that of a straw yellow. It is only when aggregated together in mass that the colour looks red, in the same way that the concentrated yellow pigment of saffron does when seen by transmitted light.

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* Chicago Medical Journal, April 15. 1869.

Size.—The size of these bodies varies greatly in different animals. The most careful and elaborate researches on this subject has been made by Mr Gulliver, who, with the animals of the London Zoological Gardens at his disposal, measured the blood corpuscles of one hundred and seventy-six different mammiferous animals, and of two hundred and four different species of birds.* The following measurements, in fractions of an inch, will give an idea of the extreme variations which exist :—

	Breadth.	Thickness.
Man	1.3200	1.12.400
Do. Fœtal . . .	1.2800	
Elephant . . .	1.2745	
Musk Deer . . .	1.6330	
	Long Diameter.	**Short Diameter.**
Camel	1.3250	1.5921
Ostrich	1.1649	1.3000
Pigeon	1.2314	1.3429
Humming Bird . . .	1.2666	1.4000
Frog	1.1108	1.1821
Crocodile . . .	1.1231	1.2286
Proteus	1.400	1.727
Pike	1.2000	1.3555
Shark	1.1143	1.1684
Earth-worm . . .	1.110	1.1200
Leech (after addition of water) .	1.3000	1.3600

The size of the coloured corpuscle bears a relation to the calibre of the ultimate capillary vessels, which are just large enough to admit of one passing in single file. Injections, therefore, of the blood vessels are more easily made in reptiles than in any other animals.

Chemical Constitution.—Hoppe-Seyler † has shewn that the blood corpuscles consist mainly of hæmoglobin, with traces of albumin, cholestrin, protagon, phosphate of potash, but no fats.

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* Appendix to his Translation of Gerber's General Anatomy, 1842.

† Hoppe Seyler, Chemische Analyse. 1870.

Effects of Reagents.—The addition of water causes these bodies to lose their colour, to swell out and become globular. Syrup, gum, albumin, and dense saline solutions, renders them flaccid, mis-shapen, irregular in outline, contracted, puckered, &c., as represented (Plate III. fig. 4). Acetic acid appears at first wholly to dissolve the mammiferous corpuscles, but their form may be faintly recognised on adding to them tincture of iodine. But on the oval corpuscles of birds, reptiles, and fish, the effect is simply to dissolve, or render very transparent, the cell wall, whilst the nucleus is unaffected, and rendered more clearly visible in the field of the microscope. (See Plate III. fig. 6, *d*). Astringent solutions, and especially a solution of crystallised nitrate of silver, causes puckerings and folds to appear in the cell wall. This is well seen in the corpuscles of the newt, and were supposed by Martin Barry to indicate the existence of a spiral filament. A solution of Magenta (the chloride of rosaniline), causes a minute molecule to appear on the external margin, as pointed out by Dr Roberts of Manchester. This I ascertained by using very high powers (1.25th of an inch focus) to depend upon minute rhomboid crystals adhering externally to the edge (Plate III. fig. 7, *a*, *b*). The same observer, also, was the first to describe the effect of a dilute solution of tannic acid (2 grains to the ℥i of distilled water), when added to the coloured blood corpuscle, causing one, and sometimes two, protrusions to take place at its circumference (Plate III. fig. 8). If, in addition to the tannic acid, tincture of iodine be added, I have seen this protusion, or an included portion of it, strongly coloured, and present the various forms represented in fig. 9.

Effects of Disease.—When the blood becomes inspissated, as in acute inflammation, the coloured corpuscle loses its rounded outline and elasticity, becomes flask shape, and instead of rouleaux, forms irregular masses, as in Plate III. fig. 5, or becomes oval, dragged out and elongated by adhering molecular fibres of fibrin (Plate IV. fig. 2). On one occasion I saw, in a case of cholera which was under the care of Dr Cowan, the remarkable appearance, figured Plate III. fig. 10. In hæmatocele, or in the act of disintegrating, the corpuscles may become fatty, and exhibit in their interior bright refracting molecules (Fig. 11). In the spleen pulp, and in apoplectic extravasations, groups of them may not unfrequently be seen to be surrounded by a hyaline substance, probably squeezed from their substances, as in Plate III. figs. 20 and 21. Leucocythemia consists of an increase of the colourless and diminution of the coloured corpuscles, as represented, Plate III. figs. 13 and 14. This morbid condition will be referred to at length in speaking of the blood glands. (See Sanguification).

Origin and Development.—The blood corpuscles in the embryo are formed in the interior of the cells of the vascular layer of the germinal membrane. In the adult, they are produced in the interior of the lymphatic or blood glands, as will be more fully detailed under the head of Sanguification.

Structure.—The opinions on this point which have been put forth are far too numerous even to be enumerated. We can only refer to the principle ones. The coloured blood corpuscle has been regarded, 1. as an animalcule (Kircher, Borelli); 2. as a globule of oil (Malpighi); 3. as consisting of six particles, each of which were formed of six smaller ones (Lewanhoeck). This was the basis of the celebrated theory of *error loci* put forth by Boerhaave; 4. as a ring with an opening in the centre (De la Torre); 5. as a vesicle containing a loose moveable nucleus (Hewson); 6. as a fibrinous solid body of a bi-concave form (Young, Hodgkin, Lister, Gulliver); 7. as a vesicle containing a nucleus surrounded by air (Schulz); 8. as a vesicle containing a semifluid colouring matter (Donné); 9. as an organised cell, containing six nuclei; 10. as a body containing a spiral filament, the elementary basis of all the tissues (Martin Barry); 11. as a vesicle, containing a nucleus attached to it by its poles, surrounded by a coloured liquid (Rees and Lane); 12. as a vesicle having a double envelope (Roberts, Hensen); 13. as a homogeneous body in the living animal, which is partly coagulated on leaving the body, its centre more especially becoming solid (De Blainville, Mandl, Savory).

Of all these opinions, I consider the last to approach nearest the truth, and that the mammiferous corpuscle, when circulating in a living animal, consists of a membrane and some solid contents. Indeed, on more than one occasion, I have succeeded, when perfectly fresh, in lacerating that membrane, and seeing the fluid contents flow out. Puckered folds may also occasionally be seen in it, especially in the corpuscles of the newt after the addition of coagulating agents. But subsequently the fluid contents coagulate, which, as De Blainville thought, are probably more dense in the centre, as in the case of the crystalline lens, and of the contents of the nerve tube. This view agrees with the great elasticity seen to exist in the corpuscle when alive—its possession of endosmose and exosmose—the influence of reagents—the central prominence demonstrated by Professor Freer of Chicago, and the escape of a glutinous matter, capable of being partly tinged by pigments, after the addition of tannic acid.

Functions.—The chief use of the yellow blood corpuscles is, by their solution, to form the liquid plasma of the blood (*liquor sanguinis*), and fit it for the important function of nutrition. At the same time, they serve, by the chemical changes they undergo in the lungs and in the capillaries, to diffuse oxygen throughout the economy, to promote thereby varied transformations between the solids and fluids, and to keep up animal heat. They further act mechanically in keeping the capillaries patent.

NERVE CELLS.—In the nervous grey matter of the brain, spinal cord and ganglia, are embedded cells, which vary greatly in shape, size, and structure.

Shape.—They may be globular or oval, as in the Gasserian and other ganglia (Plate III. fig. 28, *a*, *b*, *c*). Two processes may project from them at opposite sides, continuations of the nerve tubes, as in the ganglia on the posterior roots of the spinal nerves. They are then called *bi-polar* (Fig. 28, *d*). There may be more of them, varying from three to seven, when they are called *multi-polar*, as in the grey matter of the spinal cord (Fig. 28, *e*, *g*). They may be pear-shaped, the pointed extremity prolonged and dividing into numerous branches, as in the grey matter of the cerebellum (Fig. 28, *f*). Lastly, Dr Beale has described a peculiar form and arrangement in certain ganglionic nerve cells of the frog, pyriform in shape, having a straight and a spiral filament (Fig. 28, *h*). These have also been described by Arnold and Courvoisier.

Size.—These cells vary greatly in size, the smaller in the cerebellum being about 1.2500th of an inch in diameter, and the larger in the Gasserian ganglion often reaching the size of 1.400th of an inch.

Structure.—These cells have a distinct but delicate cell wall, outside which is occasionally seen a layer of nucleated areolar tissue. The nucleus is distinct, with one or more nucleoli, and varies as much in size as the cell does. The contents consist of fine molecules, generally colourless, but occasionally light or dark brown, which communicate to certain ganglia, such as the *corpus niger*, a brownish tint. The processes coming from the bi-polar or multi-polar cells must be regarded as continuations of the nerve tubes, whereby connections are maintained with one another, or with different portions of the cerebro-spinal or sympathetic centres. The addition of water causes them to swell out and enlarge, while acetic acid partially dissolves them.

Functions.—These cells are supposed to be connected with the evolution of nerve force. They are not the only nervous structures possessing this power, as the molecular and tubular nerve elements are similarly endowed. They also subserve the purpose of conveying, modifying, and diffusing the influence of impressions. These properties, however, are so essentially concerned with other functions of the nervous system, that they will be more fully considered when speaking of the nerve tubes. (See Tubular Elements of the Tissues.)

FAT CELLS.—The solid fat of the dead body is fluid during life, and contained within distinct cells, with delicate walls, named fat or adipose cells. When isolated, they are globular or oval in shape, but when aggregated together are polygonal, from being pressed together (See Plate III. fig. 26). They strongly refract light. The young cells vary greatly in size. They may be as small as the 1.3000th of an inch in diameter, as may be seen in the mesentery of a lean animal, or the 1.500th of an inch, as in ordinary adipose tissue. In fatty tumours they may become as large as 1.300th of an inch. On adding water to the young cell, it often enters it by endosmose, and collects between the cell wall and the oil in the interior. In this wall a nucleus may frequently be seen imbedded, and outside it crystals of margarin, which may project from the surface like a bundle of needles, or ramify on its internal surface in an arborescent form. (See Plate I. fig. 15.) The cell walls are easily ruptured, when the oil masses float in loose globules in the field of the microscope. Ether causes the cell walls to collapse and the oil to dissolve. Liquor potassæ does the same thing, leaving a brownish viscous mass. These cells are readily seen developing in young animals in the mesentery and subcutaneous areolar tissue. Minute granules collect outside the blood vessels, which, aggregating in a mass, form the nucleus. Around this the cell wall is formed, and oil accumulates in the interior, first in the form of molecules, which melt into one another. (For Chemical Composition and Origin of Fat, see Fatty Proximate Principles, p. 18.)

PIGMENT CELLS.—Variously coloured pigments are found in the interior of cells, in plants, and animals (see Pigmentary Proximate Principles, p. 30), but the term, pigment cell, is usually applied in man to that kind of cell formation which contains in its interior brown or black molecules. These are found in the choroid membrane, the lungs, and in the skin. In shape they may be globular and oval, as in the lung ; hexagonal, fusiform, or branched in various parts of the choroid, and polygonal in the epidermic cells of the dark races, and in the areola of the nipple. (Plate III. fig. 27.) The tint may vary from a faint yellow or brown to the deepest black. The pigment is always molecular, situated between the nucleus and cell wall, often obscuring, but sometimes permitting the former to be seen clear and colourless. They vary in size, from the 1.1200th to the 1.500th of an inch in diameter. In the choroid and skin, the pigment disappears on the addition of chlorine or hydrochloric and nitric acids, but in the lungs it resists every reagent, including that of the blow-pipe. In the former case, it is a peculiar substance called melanin (see p. 31), in the latter it is pure carbon. Acetic acid often dissolves the cell wall, when the pigment molecules escape and are dispersed. These pigment cells give a special character to a certain morbid growth named melanosis. The peculiar vital properties of the pigment molecules within the cells have been previously referred to. (See pp. 39 and 40.)

GLAND CELLS.—The cells which constitute the essential secreting parts of glands are too numerous to be treated of separately, and will be referred to more particularly under the function of Secretion. They vary greatly in size, structure, chemical composition, and individual properties, but are alike in possessing general powers of attraction and selection, whereby they eliminate from the blood a variety of products necessary for secretion and excretion.

TRANSITION CELLS.—Under this head it is necessary to refer to a class of cells, which, during one period of their lives, possess all the characters and properties of cell formations, but at another, pass gradually into other more complex and permanent formations. To this class belong,—

1. *Embryonic Cells.*—In the embryo, and in the early development of healthy and morbid tissues, molecules, nuclei, and cells present themselves, which exhibit no distinctive marks, but which, in the progress of development, are transformed into various tissues. Of these, the variously shaped cells seen in a recent exudation on a serous membrane, and which are subsequently transformed into blood vessels, constitute a good example.

2. *Epithelial Cells.*—These may assume various forms, such as, 1. flat or tessellated, when they adhere by their edges ; 2. columnar, when they adhere by their sides ; 3. ciliated, having cilia on their free surfaces ; and, 4. globular, which is a form of gland cell. The large mass of cells constantly forming in the internal layer of the epidermis, as they pass outwards undergo chemical and vital changes. They are thereby converted into horny matter, and aggregate together, or split up, so as to arrange themselves into hair, nail, hoof, horn, feather, scale, and, in the lower animals, especially insects, endless varieties of forms adapted to many purposes. In the mucus, covering various mucous surfaces, round or oval cells are embedded, often called mucous corpuscles, which are only a form of epithelial cell (Plate III. fig. 16).

3. *Fibre Cells.*—These corpuscles are for the most part fusiform in shape, and though isolated in the skin, are more commonly aggregated together to form layers round tubes and hollow viscera, such as certain blood vessels and the alimentary canal. They also constitute the radiating and circular fibres of the iris. Some are, and others are not, possessed of contractility ; and what is further remarkable concerning them is that, in some tissues, they may be contractile at one period and not at another. Thus, in the unimpregnated uterus they exert no contractile action, but during pregnancy, or when otherwise hypertrophied, they enlarge and become contractile, so that at a given moment they are capable of expelling the fœtus or other included body. (Plate IV. figs. 5, 13.)

4. *Cartilage Cells.*—These bodies will be described subsequently. (See Cartilage and Bone.) In the embryonic osseous tissue they are essentially concerned in the transformation of

cartilage into bone ; and although some of them are more permanent in man, it is observable that as age advances there is everywhere a tendency shewn for cartilage to pass into bony texture.

Morbid Cells.—Under the influence of irritation and other morbid causes, the cells previously described may increase in numbers endogenously or exogenously, and not unfrequently new cells are formed in matter exuded from the blood vessels. In either case, such cells may present modifications that require to be especially studied, forming as they do, essential parts of diseased processes and growths. The pathological cells are,—

1. *Pus Cells.*—Normal or good pus, when examined under a microscope, is found to consist of numerous corpuscles, floating in a clear fluid, the *liquor puris.* The corpuscles are globular in form, having a smooth margin, and finely granular surface. (Plate III. fig. 17.) They vary in size from the 1.2000th to the 1.1200th of an inch in diameter. There may be generally observed in some of them a round or oval nucleus, which is very distinct on the addition of water, when also the entire corpuscle becomes distended from endosmosis, and its granular surface is more or less diminished. On the addition of strong acetic acid, the cell wall is dissolved, and the nuclei liberated in the form of two, three, four, or rarely five granules, each having a central shadowed spot. If, however, the reagent be weak, the cell wall is only rendered very transparent and diaphanous, through which the divided nucleus is very visible (Plate III. fig. 18). Occasionally these bodies are seen surrounded by another fine membrane, as in Fig 19, and numerous diaphanous or hyaline bodies may be seen floating among them. The production of these has been previously explained. (See p. 44 and Plate II. fig. 11.) At other times they are not perfectly globular, presenting a more or less irregular margin, associated with numerous molecules and granules. This occurs in what is called scrofulus pus, and various kinds of unhealthy discharges from wounds and granulating surfaces. In gangrenous and ichorous sores, a few of these irregular pus corpuscles are associated, not only with a multitude of molecules and granules, but with transformed and broken-down blood globules, the *debris* of the involved tissues, &c., &c.

The exclusive cell pathologists maintain that pus cells originate within the nuclei of the fibrous tissues, or what they call connective tissue corpuscles. Ever since this statement was put forth, I have in vain sought among morbid products for any proof of its accuracy. My assistants and my annual practical classes of histology have made numerous observations and experiments, especially putting setons through the skin and cornea of living animals, and a few days afterwards examining the altered tissues, and have never seen pus corpuscles in the interior of these nuclei. German pathologists, firm believers in the views of Professor Virchow, have, for three months together, in my clinique, ransacked the inflamed and purulent tissues of the body, in the hope of finding and shewing me even one enlarged connective tissue corpuscle, containing pus cells, but have at length admitted that nothing of the kind could be found. I have requested all the pathologists of this city, and many of my foreign *confrêres*, to shew me in recent specimens, or in prepared preparations, any one example of such an occurrence; but notwithstanding their belief that they had seen it, they have not ventured to demonstrate to me a fact, so simple in itself, and one of such consequence to the truth of the cell pathology they support. I do not believe, therefore, that pus cells originate in the interior of other cells. On the other hand, I am at all times prepared to demonstrate, both from recent specimens and from numerous preparations, that pus cells really originate in the molecular matter of exudations from the blood vessels,—a fact that may readily be seen in a specimen of acute pneumonia, and in other examples of recent purulent formation.

Another theory of the origin of pus cells, founded on an observation originally put forth by Addison (1843),* has recently been contended for by Cohnheim, viz., that they pass bodily through the vascular walls, being in fact colourless blood cells. Ever since Addison's views on this matter were published, this phenomenon, though carefully looked for by myself and assistants, has never been observed. (See Inflammation.)

2. *Granule Cells.*—It was shewn by Reinhardt, that all kinds of cell formation, under certain circumstances, undergo the fatty degeneration. The manner in which this is accomplished is in all cases the same. A few fatty molecules first form between

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* The Actual Process of Nutrition in the Living Structure demonstrated by the microscope, &c. By William Addison, F.L.S. London, 1843.

the nucleus and cell wall. These increase in number, and some of them apparently are fused together to produce larger ones. This process goes on until at length the whole contents of the cell consist of fatty molecules and granules. The nucleus is now no longer visible, and in many cases the formation of molecules takes place within the nucleus in the first instance. In either case, the cell wall, distended by the accumulation of fatty particles, at length gives way, and the included oil granules either separate, or for a time adhere together in granular masses. Sometimes these bodies are easily ruptured by external violence ; at others they are more resistant, and the oily matter is forced through the cell wall, and collects outside, whilst the cell itself is more or less collapsed. In this way collections of fatty granules and granule cells takes place in the ducts of all glands which are lined by epithelium ; in the air vesicles of the lung and in the bronchi ; in the cells of the liver, causing fatty degeneration of that organ ; in the shut sacs of vascular glands, as the spleen, and in all cell formations from exudation, especially those of pus and cancer. Their formation constitutes the special lesion of chronic inflammatory softening of the brain. (See Plate III. fig. 22.)

3. *Cancer Cells* may be round, oval, caudate, spindle-shaped, oblong, square, heart-shaped, or of various indescribable forms, produced by pressure on their sides. In size they vary from the 1.1200th to the 1.400th of an inch in diameter. The cell wall, when young, is smooth and distended ; when old, it is more or less corrugated and flaccid. Each cell contains at least one nucleus, often two or more. Most commonly there is only one, which is round, or more generally oval, and contains one or two granules or nucleoli. The included nuclei also vary in size, and may present all stages of transformation into cells. It is the unusual facility for endogenous cell growth that communicates to cancer its so-called "malignity." (See Plate III. fig. 23.) Between the nucleus and cell wall there is a colourless fluid, which, at first transparent, becomes afterwards opalescent, from the presence of molecules and granules. On the addition of water, the cell wall becomes distended by endosmose, and is enlarged. When acetic acid is added, the cell wall is rendered more transparent, and in young cells is entirely dissolved, whilst the nucleus, on the other hand, either remains unaffected, or its margin becomes thicker, and its substance more or less con-

tracted. These cells may originate either in an exudation, or from the proliferation of previously existing cells. It is only in the former case, however, or when they become infiltrated throughout the texture of an organ that cancer can be distinguished from glandular, epithelial, enchondromatous, or other morbid growths.

4. *Tubercle Corpuscles.*—A small portion of tubercular matter squeezed between glasses, and examined under the microscope, presents a number of irregular shaped bodies approaching a round, oval, or triangular form, varying in their longest diameter from the 1.2000th to the 1.1200th of an inch. These bodies contain from one to seven granules, are unaffected by water, but rendered very transparent by acetic acid (Plate III. fig. 25). They are always mingled with a multitude of molecules and granules, which are more numerous as the tubercle is more soft (Plate III. fig. 24). Occasionally, when softened tubercle resembles pus, constituting scrofulus purulent matter, we find the corpuscles more rounded, and approaching the character of pus cells. They do not always, however, on the addition of acetic acid, exhibit the peculiar granular nuclei of these bodies. The grey granulations described by Bayle, may be seen on careful management of the light, after the addition of acetic acid, to contain similar bodies to those described as tubercle corpuscles, closely aggregated together, with their edges indistinct, and containing few granules. Tubercle corpuscles originate in a chronic exudation of the lung, under circumstances where cell formations seldom if ever occur in it. They are abortive histogenetic nuclei, and not the result of a disintegrative process, as some have supposed. (See Tuberculosis.)

The careful study, and a knowledge of the characteristic differences existing between cells, is often one of great difficulty, but should be perseveringly followed as a means of obtaining results in diagnosis and treatment of the highest importance.

The Fibrous Elements of the Tissues.

Definition.—By an elementary fibre is to be understood a solid microscopical filament, characterised optically, when round, by two broad external opaque lines, with a transparent line between them. They vary in thickness and chemical composition. Like the molecule and the cell, the fibre has been considered as the elementary basis of organisation (Haller).

The various kinds of fibre may be classified histologically into molecular, nuclear, and cell fibres, all of which may be non-contractile or contractile.

MOLECULAR FIBRES.—1. *Non-contractile molecule fibre* may be seen in mucin and in the clot of blood (Pl. IV. figs. 1 and 2) to be composed of rounded molecules, agglutinated together end to end. In a layer on the surface of rheumatic or inflammatory blood, molecular fibres may be seen to form under the microscope, as pointed out by Dr Addison, now of Brighton. In the clear fluid, a deposition of molecules occurs, which arrange themselves in rows, stretch across the field of the instrument, and at length render the whole opaque, and constitute the fibrinous coagulum of the clot. The same occurs in mucin.

2. *Contractile molecular fibre.*—We have previously seen (p. 46) that on the surface of an infusion, molecules arrange themselves in short rows, melt together, and assume a vibratile movement. As they grow longer, the motion becomes serpentine, and they dart or wriggle rapidly through the fluid. These are the so-called *vibriones* or *spirilla.* In this manner actively moving and contractile filaments form by apposition of molecules, without the agency of nuclei or cells. (Plate IV. fig. 11.) The addition of acetic acid generally causes partial solution of these fibres.

3. *Striated muscular tissue.*—The most important form of molecular contractile tissue, is the striated or voluntary muscular fibre. This in its turn is made up of numerous smaller fibrils or *fibrillæ*, and hence is called a *fasciculus.* Each muscular fibre or fasiculus is polygonal in shape, as is readily seen on making a transverse section of a group of them (Pl. IV. fig. 18). Their average diameter in man is about the 1.352d part of an inch, and in woman about 1.454th part. They are much broader in fishes, and much narrower in birds. They are surrounded by a delicate, structureless membrane, first demonstrated by Bowman, and called by him the *Sarcolemma.* It may be shewn by strongly irritating the living fasciculus, whereby its sarcous structure is ruptured, leaving the membrane entire (Fig. 22), or by adding to it water, when the membrane is raised by imbibition in the form of bullæ on the surface, as in the lower portion of Fig. 23.

The transverse striæ consists of alternate dark and light lines running across the fasciculus. These describe the curve presented to the eye, being generally rounded, but not unfrequently angular, if an angle of the polygonal outline of the fibre lie upwards. The striæ are finer, that is closer together, in fishes, and coarser or wider in the crustaceæ. In certain conditions of the fasciculus it readily breaks across in the direction of the striæ (Fig. 19); in others, lengthways in the direction of the fibrillæ (Fig. 20). When these last are isolated, it may be seen that each is made up of alternate light and dark particles of a square or oblong shape (Fig. 24). The structure of these was first shewn by Dr Dobie of Chester,* to consist, under high magnifying powers, of dark and light markings, occupying the entire breadth of the fibrillæ, the light one being again divided by a delicate dark line (Fig. 25). This remarkable appearance characterises the finest fibrillæ that has yet been arrived at by the most skilful manipulations that can be practised, as seen under a power of 2000 diameters linear. Acetic acid renders more transparent the whole substance of the fasciculus, and brings into view nuclei, varying in size and shape, embedded in its substance (Fig. 21).

If, immediately after killing an animal, a fasciculus be rapidly placed on a glass slide, and examined under a microscope, it may be seen, when irritated, to contract and shorten itself, by the striæ becoming thinner, flattening themselves against each other, and causing a corresponding thickening of the fasciculus, as in the lower portion of Fig. 23. Sometimes this takes place uniformly throughout the whole length of the fasciculus; at others, at one extremity, and occasionally here and there causing alternate swellings. Friction on the glass may produce these last effects. Formerly it was supposed that the fasciculus was shortened by a zig-zag movement. But this appearance is now recognised as a proof of extreme relaxation in muscle.

The structure of Muscle.—Various opinions have been held on this subject. The older histologists considered the striæ to be caused by puckerings or edges in the external sheath; but all recent observation with good achromatic microscopes demonstrate that they are caused by the regular apposition side by side of the dark and light particles of the ultimate fibrillæ. The cohesion of these is such that sometimes they separate cross-ways to the fasciculus, forming disks ; at others, long-ways, producing minute fibres. (See Pl. IV. figs. 19 and 20.)

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* "Annals and Magazine of Natural History." 1849.

Chemical composition of Muscle.—A quiescent muscle gives an alkaline reaction, but when the muscle is tetanised, the reaction becomes acid from the development of lactic acid. Helmholtz has found that, by tetanisation, the substances soluble in alcohol are increased, while those insoluble are diminished. The semi-fluid, contractile substance of muscle, when isolated from sarcolemma, divides, according to Kühne,* into a fluid portion, which he terms muscle-serum, and a solid coagulum, which he terms muscle-clot, or myosin. The muscle-serum contains three forms of albumin, one coagulating at 30°, a second coagulating at 45°, and a third at 75° C. Myosin has been already described in treating of the chemistry of the tissues. (See p. 10.) An analysis by Von Bibra shews that 100 parts of muscle, freed as much as possible from fat, nerves, and vessels, yielded, when burnt, from 2 to 8 parts of ash, and that about 90 parts of this ash consisted of alkaline and earthy phosphates, and the remaining 10 parts consisted chiefly of chloride and sulphate of sodium. The muscular substance of the heart is remarkable for containing inosite, which is not found in other muscles. Living muscles consume oxygen, and excrete carbonic acid. By the oxidation of the nitrogenous material in muscle, creatin, creatinin, hypoxanthin, taurin, leucin, &c., are produced.

The development of striated muscular fibre has long been a subject of discussion, and by the upholders of a cell theory has been supposed to originate in an apposition of cells, or a deposition in their interior. Dr Wilson Fox is the last observer who has maintained this opinion (1865). But the careful investigations of Savory, confirmed by those of Lockhart Clarke, Braidwood, and Eckhard, have proved that they are formed by the coalescence of the molecular matter of the intercellular substance, several of the embryonic cells and nuclei remaining embedded in the substance of the fasciculus. (See Pl. IV. fig. 26, and description of plate.) This view once recognised, it may be observed, on consulting the accurate figures published by Schwann and Bowman, that the facts that they have placed on record are in accordance with the molecular origin of voluntary contractile fibre.

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* Kühne, Myologische Untersuchungen, 1860.

NUCLEAR FIBRES.—*Elastic or yellow fibrous tissue* is formed of nuclear fibres. They vary greatly in thickness, from the 1.10,000th to the 1.3000th of an inch in diameter. In the *ligamenta subflava* of quadrupeds they may frequently be seen to anastomose with one another (Pl. IV. fig. 3). In the giraffe, as pointed out by Quekett, they often present transverse markings, owing to small spaces in their substance. Their extremities have a tendency to curl up, and they may frequently be seen, as figured by Henle, forming distinct spirals, especially in the fibrous tissues at the base of the brain (Fig. 4). The addition of acetic acid produces no change in these fibres, so that they present the chemical reaction of the nuclei of cells. Their mode of formation, according to Henle, is from an elongation of the nuclei in neighbouring cells, which, coalescing together, and sending off branches which unite with one another, produce this anastomosing elastic fibre. The spiral he thinks is produced by the nucleus frequently being on the opposite sides of neighbouring cells, so that, in order to unite, they are obliged to cross and wind round the interior of the cell (Fig. 8). The spirals in the cells and ducts of plants are probably formed in a similar manner.

Chemical composition.—The chief proximate principle found in elastic tissue is elastin, which has been already described (p. 11).

Several fibres, evidently developed from a nucleus, possess contractility. The spiral or zig-zag fibre in the stalks of vorticellæ, the spermatozoid in animals (Pl. IV. fig. 12), and the antheroid moving particles in plants, are evidently of this kind.

CELL FIBRES.—*Areolar or white fibrous tissue* is the most characteristic example of this kind of fibre (Pl. IV. fig. 6). It consists of filaments, varying from the 1.16,000th to the 1.8000th of an inch in diameter, running in wavy parallel lines, in bundles, which often, by crossing one another, leave spaces or areolæ. In ligament and tendon, however, they are more condensed together. On the addition of acetic acid, they are for the most part rendered partially soluble, and very transparent, like the substance of cell walls. They are developed, as was shewn by Schwann, by the splitting up of cell walls (Pl. IV. fig. 9), the nuclei often remaining scattered among the fibrous bundles, and becoming very perceptible after the action of acetic acid, which does not affect them (Fig. 7). The various fibres found in the epidermic appendages of hair, horn, feather, &c., are developed in the same way, although a chemical change occurs in them, by means of which some of them are rendered insoluble in acetic acid (Fig. 10).

Although this is the usual method whereby the white areolar fibres are developed, I have no doubt that they may be occasionally produced by the splitting up of intercellular substance (Henle), or by superposition of molecular substance around the nucleus (*Epigenesis* of Robin).

Chemical composition.—Areolar tissue contains a large amount of water, and loses much of its weight by drying. It consists almost wholly of gelatin.

2. *The contractile cell fibres* are seen in the so-called non-voluntary muscular coats of hollow viscera (Pl. IV. fig. 13). Here the cells elongate into a fusiform or spindle-shaped body, and, flattening and uniting at their edges, form riband-shaped bands, of which the structure is made up. On the addition of acetic acid they are seen to be studded with oval or elongated nuclei (Fig. 14). Each individual cell has the property of shortening its length and swelling out laterally, thus producing contraction of the tissue. These same cells, isolated or grouped together, are the origin of contractions in various textures, such as the iris, the dartos, the uterus, &c. (see p. 68). In the last-named organ, during pregnancy, they are greatly enlarged, and, though not contractile previously, they assume that property for the purpose of expelling the fœtus, or other uterine contents—which accomplished, they undergo fatty or molecular histolysis and disappear.

Numerous other examples of contractility in cells may be observed among the infusoria, in the embryonic hearts of numerous animals, and especially in cilia, which must be regarded as a form of contractile cell fibres.

3. *Cilia* are contractile fibres resembling in shape the hairs of the eyelashes: hence their name. They are widely diffused in the animal kingdom, covering the bodies and respiratory organs, or surrounding the oval aperture in infusorial, molluscous, and other animals. In man they cover the lining membrane of the nasal passages, the Eustachian tube and cavity of the tympanum, the trachea and bronchi, the cavity of the uterus and Fallopian tubes, and the ventricles of the brain. Each cilium is like the blade of a sabre in shape, that is, flat and slightly curved, having a point and broad base where it is fixed (Pl. IV. fig. 16). They

are clear and structureless. When observed in action, they move backwards and forwards something like growing grain when agitated by the wind. Their vibrations, however, are more rapid, amounting to seven hundred in a minute. As the movements become slower, it can be seen that they beat the water broadways, and turn their edge, in coming back, like the action of feathering the oar by a boatman. They die from the base upwards, the top continuing to move sometime after the base is motionless. (Pl. IV. figs. 15 and 16.)

It has been supposed that each cilium is moved by two minute muscles inserted into its base (Ehrenberg); that it consists of a double spiral, which is continually winding and unwinding itself (Barry); or that it is due to imbibition of nutrient fluids (Beale). But neither muscles nor double spiral can be seen with our highest magnifying powers, and the peculiar and rapid to and fro movements in fluids are inexplicable on the supposition of imbibition. It must depend on an inherent power, the nature of which is essentially vital. (See Contractility.)

Histolytic Fibres.—The term histolytic may be applied to those fibres which result from a disintegrative process, such as may be seen in cartilage, where, as the result of molecular changes in the intercellular substances, it splits up and fibrillates, as seen in Plate VI. figs 3 and 4. It has been well figured and described by Redfern in the morbid changes occurring in joints. Such histolytic molecular changes occurring in cartilage may also be observed occasionally to give rise to histogenetic fibres, as takes place in many forms of fibro-cartilage, and in some of those productions denominated by Dr Handfield Jones, "fibroid degenerations,"—a fact which strongly supports the molecular theory of organisation and the alternate function of histogenetic and histolytic elements.

Function of the Non-contractile Fibres.—The molecular fibres of blood and mucin can only serve to give consistence to those fluids when exuded into tissues or collected on surfaces, and to entangle the cells together so as to favour their histolytic action. The nuclear or elastic fibres serve to connect joints, and to give greater firmness and elasticity to certain tissues. They restore parts after they have been moved by muscular action, and hence in various places they supply an antagonistic force to muscles. The areolar or cell fibrous tissue unites other elements, binds together groups of cells, offers an elastic medium permitting motion, and serves as a matrix to protect the blood vessels and nerves as they ramify through the frame. In tendons, it acts as the rope of a pulley ; in ligaments, as uniting joints ; in aponeuroses, as a firm membrane for the insertion of muscles ; and in integument and investing membrane, as a firm protective envelope to the body or to various viscera.

In recent times a new function has been ascribed to these fibrous tissues which here requires notice. Reichert was the first to group several of them together under the name of *connective tissues*, because they lie between and so far connect, or as Kölliker more correctly states, support, various histological elements. It was supposed that they were united together or continuous throughout the organism, and served as a substratum or basis tissue to all parts of the body. Kölliker so far differs from this view, as to consider that it is not so much their anatomical union as the genetical connection between them and their correspondence in function which keep them together. But when it is considered that these connective tissues are said to be the vitreous humour of the eye ; mucous tissue as it is found in the umbilical cord and in the lower animals ; the gelatinous tissues of the embryo ; the areolar and elastic tissues of the adult, with their various modifications, as observed in tendon, ligament, aponeuroses, &c. ; as well as the tissues of cartilage, bone, and even of tooth,—the idea of grouping them together, on the ground of either structure or function, seems most arbitrary. If the term connective tissue be limited to tendon, ligament, elastic or areolar tissue, which unite and connect together important parts, there can be no objection to its employment ; but to call a tooth, or the vitreous humour of the eye, also, connective tissue, can only lead to confusion of facts and ideas .

But Virchow has even still further extended this group of the connective tissues ; for, in addition to those previously named, he holds that fat, cornea, and the grey substance of the brain are also connective tissues. In this manner, connective tissue may be structurally fibrous in ligament, cellular in fat, hyaline in cartilage, and molecular in the grey substance of the brain. Chemically, it may be chondrin in cartilage, albuminous in tendon, horny in cornea, peculiar in elastic tissue, and mineral in bone. Hence the most diversified substances as to structure, chemical composition, and vital and physical properties are associated together. What other histologists consider solid fibres, Virchow regards as hollow tubes, and says they serve to convey a nutritive fluid to all parts of the economy. And again, what are almost universally thought to be nuclei, he maintains are cells (connective tissue cells), and declares them to be the origin of all healthy and morbid formations. This last view I shall again allude to. But with regard to the solid fibres of areolar and elastic tissue being tubes, an examination of a transverse section of a tendon will at once disprove the statement, for there the ultimate fibres of which we have spoken can be seen, with a sufficient magnifying power, to have no cavity, and, therefore, to be solid. It is true that the bundles of these fibres frequently have little spaces where they meet, with three or four angles having divisions leading between the bundles. These, as pointed out by Henle, explain the appearances in tendon referred to by Virchow, and account for the mistake he has committed.

We must conclude therefore that no such system of tubes as have been supposed by Virchow, exist in the fibrous tissues generally. In bone, certainly minute canals are visible, and we can see coloured fluids run into them. Nothing of the kind exists in the fibrous tissues, vitreous humour, or brain, nor is there any ground for belief that the nutrient fluids which permeate the tissues are derived from any other source than the blood vessels, or that these latter are assisted by a supplementary circulation. Dr Beale, after careful investigation of this subject, has arrived at the same conclusion.

Function of Contractile Fibres.—The nature of contractility as a vital action will be subsequently considered. (See Vital Properties of the Tissues.) Here it is only necessary to point out that the textures endowed with it, when stimulated, either directly or indirectly, first contract in consequence of a closer aggregation of the molecules of which they are composed, and subsequently relax, when they return to the condition which characterised them when at rest. This power is utilised in the animal economy in various ways. In the lowest forms of animal and vegetable life, it permits of change of place, by causing serpentine, or alternate movements, which, overcoming the force of resistance in fluids or solids, permits of locomotion. In cilia, a similar result may take place if they are attached to small bodies, but if fixed to large ones or extended surfaces, they induce currents in the fluids which cover them. In isolated nuclei, or cells scattered through the skin, it induces contractions, puckerings, erections of the hair or feathers. When the tissue is arranged in layers, as in the iris or round hollow viscera, it induces contractions and dilations in apertures or organs. In the voluntary muscular system generally, when co-ordinated by the nerves and nerve centres, it occasions reflex and voluntary movements. All kinds of contractility may be excited by direct irritants, while some act in obedience to certain nervous influences, and others to different ones. The voluntary muscular fibres possess contractility in the highest degree, and hence their study, as influenced by varied conditions, is one of the greatest importance.

Effects of irritants on muscles.—Some substances easily cause contraction of muscles when applied directly to them, even if greatly diluted ; whereas to produce the same effect through the nerves, they require to be concentrated. Among these are —the mineral acids, especially muriatic and nitric acids ; the basic salts, as chloride of sodium, chloride of potassium, chloride of lime ; as well as some organic substances, as acetic acid, lactic acid, and glycerine. A second class of substances induce contraction equally, whether applied to the nerve or to the muscle. Among these are caustic potash and soda. A third class of chemical substances act powerfully on the muscle, but not at all upon the nerve ; such as chromic acid, sulphate of copper, chloride of iron, basic and neutral acetate of lead, lime, and, above all, ammonia. A fourth class of substances act exactly in an opposite manner—that is, upon the nerve, but not on the muscle, or very slightly so ; such as creasote, alcohol, concentrated glycerine, and undiluted lactic acid. Finally, a fifth class exists which have no power of producing contraction when applied to either muscle or nerve ; such as the fatty oils and turpentine.* When the sensibility of the muscular nerves has been quite destroyed in various ways, it was shewn by Wittich that contractility could be powerfully induced on injecting water into the blood vessels.

The amount of contractility in different muscles is influenced

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* See Kühne in Archiv. f. Anat. und. Phys. 1859.

—supposing them to be equally contractile and healthy—by the amount of resistance they have to overcome, and by their static force. In the individual muscles of animals this can be determined with exactitude by hanging to them different weights, causing them to contract suddenly by galvanism, and marking off the result by means of Pflüger's myographion. (See Practical Physiology.) The efforts of particular muscles when performing complex actions, however, it is very difficult to estimate.

Effects of poisons on muscles.—Strychnine, as is well known, excites powerful tetanic spasms in muscles. Coniene causes paralysis, which, in man, has been shewn to commence in the lower extremities and proceed upwards.* Other poisons influence more especially particular muscles : such as aconite, which operates on the heart ; lead, on the extensors of the arms ; cantharides, on the urinary bladder ; secale cornutum, on the pregnant uterus, &c. Bernard shewed that with curara the motor nerves might be paralysed without affecting the muscular contractility ; and Kölliker has demonstrated that veratrine destroys the contractility without affecting the motor nerves. Both poisons operate through the circulation. These facts serve to confirm—although in no way necessary—the Hallerian doctrine of irritability.

Evolution of electricity by muscles.—All muscles evolve a constant stream of electricity, which may be shewn by a multiplying galvanometer to pass from the long external surface, which is positive, to the transversely cut section, which is negative. This current is strongest in inactive muscles, because when stimulated to contract, the intensity of the current is sensibly diminished. (See Animal Electricity.)

Effects of electricity on muscles.—If a continuous stream of electricity is sent through a muscle, contractions take place at the moment of opening and shutting the circuit ; otherwise no effect is produced. These contractions are the more powerful the less the muscle is fatigued. One electrical shock sent through a muscle may last only the one-thousandth part of a second. The contraction of the muscle produced does not occur so rapidly, but reaches its maximum and returns to its former state in one-fourth of a second. If two shocks are given, the second immediately after the muscle has returned to a state of rest then there are two contractions. If the second shock is given during the operation of the first, and the muscle is either shortening or lengthening, it causes increased shortening. But if the second stroke follow very rapidly on the first—that is, within the six-hundreth of a second—the shortening is not greater than with one stroke. If several shocks are given before a muscle has time to be relaxed, it becomes hard and permanently contracted, constituting *tetanus.* (See Practical Physiology.)

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* See the Author's Case of Poisoning by Hemlock, "Principles and Practice of Medicine," 5th edition, p. 459.

Muscular fatigue.—The stronger the contractions, the oftener they are repeated, and the greater the resistance muscles overcome, the sooner are they fatigued. Much also will depend on the general nutrition of the economy, and on conditions connected with the motor and sensory nerves. Thus the muscles of a strong man are not so easily fatigued as those of a weak one. In fever, the muscles, without any exertion, reach the greatest degree of fatigue or weakness.

Cadaveric rigidity is characterised by loss of contractility, elasticity, and of electro-motor power. Its cause is now generally attributed to the coagulation of the muscular substance, which in the living body is partly fluid (Brücke). It commences in the neck and pharyngeal muscles, then passes to those of the face, then to the upper extremities, the trunk, and lastly to the lower extremities. The heart is rigid very early. The time of its duration varies greatly, and occurs from a quarter of an hour to eighteen hours after death. It may last from some hours to five or six days. The longer it is in appearing, the longer generally it lasts. It is often very slight, and after death, in animals long driven, or dying after being chased, or from severe convulsions and certain poisons, or killed by lightning, it is scarcely perceptible. The disappearance of the rigidity takes place in the same order as it came on, that is, from above downwards. On its cessation, putrefaction and real death of the tissues commences.

The Tubular Elements of the Tissues.

Definition.—By a tube is understood, as an element of the textures, a microscopical filament composed of a wall and contents. Optically it is distinguished from a fibre by one or two thin lines on each side, gradually passing into a broad light space in the centre.

Varieties of tubes.—These are numerous in plants, where they constitute the various ducts—simple, dotted, reticulated, spiral, and scalariform—and laticiferous tissue. In animals we may divide them into Air, Blood, Dental, Bone, and Nerve Tubes.

Air Tubes.—The larger air and blood tubes, such as the trachea and bronchi on the one hand, and the large arteries and veins on the other, must not be regarded as elementary tubes, but as hollow viscera, being composed of various laminæ or coats. Their ultimate ramifications, however, become more simple. The air tubes are strengthened in the higher animals with rings or nodules of cartilage, so as to keep them permanently open ; and in the lower animals, especially insects, as in plants, they present a spiral fibre in their interior, so that they are always patent. (See Respiration.)

Blood Tubes.—A minute examination of the blood vessels, including the lymphatics and lacteals, has enabled the histologist, following Henle, to demonstrate in them one or more of the following layers. These, as seen in a larger artery, may be enumerated as follows, from within outwards,—

1st. The internal layer presents all the characters of pavement epithelium, the cells varying in shape, and being occasionally fusiform.

2d. The next layer is a transparent, delicate, and fragile membrane, which easily rolls upon itself. It is distinguished by long, occasionally branched nuclei, running transversely, with round or oval openings of various sizes perforating the layer. It is called the striated, perforated, or fenestrated membrane, and is occasionally absent (Plate. V. fig. 2, *a*).

3d. The third layer is characterised by longitudinal lines which are in no way changed by acetic acid. It is formed of one or more layers (Plate V. fig. 3, *a*, *a*, and fig. 6, *t*, *t*, *t*).

4th. The fourth layer is distinguished by short transverse lines, which alternate with each other. It is much developed in large vessels, and constitutes, with the third layer, what is called the middle coat (Plate V. fig. 3, *b*, *b*, and fig. 6, *b*, *b*).

5th. The fifth layer is only found in the larger vessels, and is simply yellow elastic tissue (Plate V. fig. 4).

6th. The sixth layer is composed of white areolar tissue, the fibres of which are arranged longitudinally, having scattered here and there among them persistent nuclei (Plate IV. figs. 6 and 7).

The satisfactory separation and demonstration of these different layers requires great care. Some are better seen in the arteries than in the veins, or in vessels of a particular size. A little experience, however, will satisfy the observer of the correctness of Henle's description.

As the blood-vessels are traced towards their capillary terminations, they gradually lose their elastic and areolar coats. In small arteries, we see them almost wholly composed of fusiform cells, arranged in two layers, longitudinal and circular. (Pl. V. fig. 3). Sometimes these cells assume a spiral form round the internal layer, as shewn by Mr Lister (Fig. 5). At other times they blend together (Fig. 2), and in the ultimate capillary we observe only a simple membrane, having oval nuclei imbedded in it (Fig. 1). Such membrane is admirably fitted to permit of transudation through it of the nutritive fluid essential for the maintenance of the animal structures.

Contractile movements of blood tubes.—The blood tubes are evidently contractile, and capable of diminishing or enlarging their calibres under the action of various stimuli, such as mechanical and chemical irritants on the one hand, and peculiar nervous influences on the other. Thus, friction, cold, chemical astringents, and warmth produce pallor or redness of the surface, and similar effects are occasioned by the mental emotions of fear and shame. Mr Lister was the first clearly to demonstrate on the minuter arteries contractile fibre cells, to which he attributed the effects, and to these only he limits the contractile property. I am satisfied, however, from many careful observations, that this property especially belongs to the ultimate capillaries, which I have seen, under stimulation, diminish to one half their calibre, so as to squeeze out and prevent the reentrance of the coloured corpuscles. The experiments of John Hunter led him to conclude that the elastic property is strongest in the large, and contractility strongest in the smallest vessels, an opinion which the more minute histological observations of modern times have proved to be correct.

The development of blood tubes may be readily followed in the vascular layer of the germinal membrane, and in certain serous exudations, where the cells may be seen of a triangular or varied shape, throwing out processes to unite with one another and form a capillary plexus (Pl. V. fig. 7, *a*, *d*, *e*, *f*). Subsequently, fusiform cells can be observed aggregated around them to produce the different layers (Fig. 7, *c*, *b*).

The function of the blood tubes is to permit the blood to be distributed to all parts of the organism. The coloured or red blood passes out by the arteries and inwards by the veins. The capillaries or intermediary vessels so subdivide it as to permit the corpuscles to carry oxygen to the tissues, and these last to effect exchanges between themselves and the blood. The delicate homogeneous structure they present admirably fits them for acting as fine filters subject to vital laws, retaining the solid corpuscles and granules, and allowing only the fluid portions to transude. The lymphatics and chyle vessels convey the colourless or white blood from the tissues and alimentary canal towards the large veins in the neck, where they join the circulation near the heart, a function in which, like what occurs in the veins, they are greatly assisted by the numerous valves in their interior.

DENTAL TUBES.—On making a section of a tooth, it is seen to consist, 1st, internally of a *pulp* which is richly supplied with blood vessels and nerves ; 2d, of the *ivory* or *dentine*, constituting the chief bulk of its substance ; 3d, of *enamel*, which forms a layer over the crown ; and 4th, of the *crusta petrosa* which surrounds the root.

The pulp consists of fat cells, united together by a small amount of areolar tissue, among which a rich plexus of blood vessels are distributed and numerous terminal loops of the dental nerve.

The ivory or dentine is a firm substance, consisting of an animal basis impregnated throughout with phosphate of lime. On examining a thin section of it under magnifying powers, minute tubes are seen radiating through it, and passing from the central cavity to the circumference (Plate V. fig. 10, *a*). They are about the 1.10,000th to the 1.5,000th of an inch in diameter, run in parallel lines, and occasionally send off lateral branches. They terminate abruptly at the line of junction between the dentine and enamel above and dentine and crusta petrosa below. A transverse section shews them to possess a distinct wall, with a space in the centre (Fig. 9). Mr Tomes describes a pulpy substance as filling these tubes, which he considers to be nervous in its nature. But, as stated by Dr Beale, it is more probably coagulated nutritive matter.

The enamel, at one time tubular, in the adult is composed of solid prisms, the phosphate of lime having invaded every available space. It is therefore harder,—containing more mineral and less animal matter,—than dentine. On making sections through it in various directions the solid prisms may be seen running vertically outwards in straight or wavy lines (Plate V. fig. 8, *a*). A perfectly transverse section shews them to be closely compressed together, and of an hexagonal form (Plate V. fig. 11).

The crusta petrosa is in fact a layer of bone which surrounds the root of the tooth (see Bone). (Pl. V. fig. 10, *b.*) When young, this texture may frequently be seen to be forming, by the apposition of rounded solid masses, formerly called bone cells, in the centre of which is a nucleus or cavity, that constitutes the lacunæ of the structure (Plate V. fig. 12).

Chemical composition of Tooth.—The dental tisues consist of certain inorganic matters united with an organic basis. In crusta petrosa the organic basis is the same as that of bone. The organic matter of dentine is resolved by prolonged boiling into gelatin, while that of enamel does not yield gelatin, but a substance allied to the chemical basis of epithelium.

The proportion of inorganic to organic matter, and the composition of the former will be seen from the following analyses by Von Bibra.*

	Phosphate of Calcium and Fluoride of Calcium.	Carbonate of Calcium.	Phosphate of Magnesium	Salts.	Inorganic Matter.	Fat.	Organic Matter.
Enamel—							
Man, molar	89·82	4·37	1·34	·88	96·41	·20	3·59
Woman, molar	81·63	8·88	2·55	·97	94·03	Trace	5·97
Horse, molar	89·01	1·19	1·95	·60	92·75	·19	7·25
Dentine—							
Man, molar	66·72	3·36	1·08	·83	71·99	·40	28·01
Woman, molar	67·54	7·97	2·49	1·00	79·00	·58	21·00
Ox, incisor	58·33	7·39	0·97	·75	67·44	·52	32·56
Crusta petrosa—							
Ox, incisor	58·00	7·22	·99	·73	66·94	·95	33·06
Whole teeth—							
Pike	63·98	2·54	·73	·97	68·22	1·18	31·78

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* Von Bibra. Chem. Untersuch. über die Knochen u. Zähne. 1844.

The function of these different textures in a tooth is evidently to combine firmness and hardness with the power of keeping up nutrition. The enamel resists pressure and the friction necessary in the act of mastication. Through dentine tubes the nutritive matter is conveyed from the vascular pulp to all parts of its substance, while the softer crusta petrosa firmly wedges the tooth in its socket, and diminishes the effects of jars and concussions. Where, in the teeth of the lower animals, two or more of these substances reach the surface, attrition acts upon them differently, keeping the edges of the incisors sharp, as in the rodentia, or the surface rough, as in the graminivora.

Bone Tubes.—Though the osseous, like the dental texture is characterised by its tubular arrangements, the complex structure it presents renders its classification difficult. Cartilage is essentially a cellular tissue, yet its relation to bone forces upon us the necessity of describing them together in this place.

Cartilage or gristle is an opaque, non-vascular substance of pearly or bluish white colour, approaching towards yellow. It is easily cut with a sharp knife, yet possesses tolerable density. It is highly elastic, and in thin slices is translucent. In the early embryo and young animal, the skeleton is mostly cartilaginous, and is afterwards transformed into bone. Such cartilage is called *temporary*. *Permanent* cartilage covers the articular surfaces of joints, and is present in the costal cartilages, the external ear, the extremity of the nose, eyelids, the Eustachian tube, the larynx, and the trachea. In all these situations considerable firmness, united to elasticity, is given to the parts, although they become more rigid as life advances towards old age. The structure somewhat varies in articular, costal, and fibro-cartilage.

Articular Cartilage.—A thin section cut parallel with the surface of a joint consists of rounded or oval isolated cells embedded in a semi-translucent hyaline substance. If cut vertically with the joint, the cells, as they approach the bone, may be seen to arrange themselves in groups of twos and fours, sometimes side by side, at others, lengthways (Pl. VI. figs. 1, 9, *b*, *c*, *d*, *e*, *f*). The cells are nucleated often with nucleoli, and present great varieties in size and development. They are unaffected by re-agents. The hyaline or intercellular matter presents no structure under ordinary circumstances, but when diseased exhibits a tendency, first to become opaque and molecular, and subsequently fibrous.

Costal Cartilage.—A transverse section of costal cartilage always displays a point of ossification in its centre similar to what exists in fœtal bone (Pl. VI. fig. 11). Towards the circumference, isolated cells may be seen embedded in the clear intercellular substance, but towards the bony centre they may be seen to arrange themselves, first in groups, and then in rows radiating from that centre. A section of the structure at this point exhibits the primary changes of cartilage passing into bone (Plate VI. figs. 12, 13, 14).

Fibro-Cartilage is well seen in intervertebral substance, the epiglottis, and cartilages of the ear. The intercellular substance in this case is composed of fibrous tissue, and the greatest diversity may exist as to the respective amount of cells and fibrous elements in various places. There may be many cells and few fibres, or nearly the whole texture may be fibrous, and the cells few and far between (Plate VI. fig. 3).

Fœtal Cartilage.—In the early embryo, cartilage is mostly cellular, the hyaline substance increasing in amount and separating the cells as development proceeds. The same modifications in structure are observable in the lower animals, as in the ear of the bat and mouse, in the cuttle-fish, lamprey, &c., &c. The changes which occur in fœtal cartilage on its transformation into bone will be subsequently described.

Diseased Cartilage.—When cartilage is injured or irritated, both the cells and hyaline substance undergo marked alteration (Redfern). The former enlarge, new cells form in the interior by division and subdivision of the nucleus (proliferation), and tertiary, or even quaternary cells may be formed within this (Plate VI. fig. 9, *g*, *h*). On the distension of the original cell wall, by the young included cartilage cells, the former may burst, liberating the secondary or tertiary cells. These diffuse themselves in the intercellular matter which becomes swollen and pulpy, and subsequently breaks down, producing the degenerations and abrasions so characteristic of diseased cartilage (Fig. 5). The hyaline or intercellular matter at the same time, first becomes turbid and opaque, and then splits up into fibres, which add to the disintegration process in the tissue, causing the villous changes on the surface, characteristic of chronic white swellings of a joint (Plate VI. figs. 4, 8). Hypertrophy of cartilage, especially in the form of tumour, is called *Enchondroma.*

Chemical Composition of Cartilage.—About sixty parts in the hundred of permanent cartilage consists of water. By prolonged boiling in water, cartilage is resolved into chondrin, which gelatinises on cooling. The gelatinous mass also contains gelatin derived from the fibrous tissue which is usually associated with cartilage. The temporary cartilages are resolved by boiling into a substance resembling chondrin, but differing from it in not congealing when allowed to cool. The ash of cartilage consists of carbonate of soda, sulphate of soda, carbonate of lime, and other salts, the relative proportion of which will be seen in the following analysis by Frommherz and Gugert * :—

Analysis of Ash of Cartilage—100 *parts.*

Carbonate of soda, . .	35.07
Sulphate of soda, . .	24.24
Chloride of sodium, . .	8.23
Phosphate of soda, . .	0.92
Sulphate of potash, . .	1.20
Carbonate of lime, . .	18.37
Phosphate of lime, . .	4.06
Phosphate of magnesia, . .	6.91
Oxide of iron and loss, . .	1.00
	100.00

Bone.—On making a longitudinal section of a long bone, and examining it with a low power (20 diameters), it presents the appearance represented, Plate VI. fig. 6. That is canals running lengthways, and freely communicating with one another, embedded in a finely dotted structure. These canals are those of Havers. On now examining the same structure with a higher power (200 diameters), we observe the appearance represented, Fig. 8. The canals, of course, are larger to the eye, but the dots appear as oval or fusiform opaque spots, with fine lines radiating from them and connecting these spots with one another. These are the *lacunæ* of bone, rendered opaque by the debris or sawdust produced by grinding the preparation, and their connecting *canaliculi.* If now we look at a transverse section of the same bone, magnified 200 diameters, as in Fig. 7, we see the large openings which are the Haversian canals cut across, sometimes clear, at others opaque from accumulated and adherent sawdust. The arrangement of the lacunæ in concentric circles round these canals is also observable, the canaliculi of the internal row communicating with the large Haversian canal, and the others with successive lacunæ until the terminal or external row is reached. It is thus demonstrated that there is a channel of communication between the vascular lining membrane of the Haversian canal, through the minute tubes or canaliculi and lacunæ, to the distant concentric circles of each system pervading the osseous texture.

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* Quain's Anatomy, 7th ed. Vol. I. p. lxxxiv.

The lacunæ, with the tubes or canaliculi leading from them, vary considerably, in form and length, in various parts of the osseous texture, and especially in the bones of different animals. The lacunæ in man are of fusiform shape, and have an average length of 1.1800th to 1.2000th of an inch in length, and they are usually half as long again as they are wide. The variations, however, that may exist in their size and forms, as well as in the arangement and differences in the canaliculi, are shewn, Pl. VI. Fig. 10, *a*, *b*, *c*. *d*, *e*. The general mode of the communication between the lacunæ is seen in Fig. 10, *f*.

The hardened tissue between the lacunæ and canaliculi, is supposed by Sharpey to be composed of crossed fine reticular fibres, which is probable, though difficult to demonstrate. Tomes thinks it is made up of very fine earthy molecules agglutinated together. Both opinions may be conjoined, for as the intercellular substance of cartilage is the basis of bone, and this, as shewn by Leidy, has a fibrous arrangement, the fine mineral molecules of phosphate of lime deposited in it must make up the ultimate osseous tissue. Quekett endeavoured to shew a relation between the size and form of the osseous lacunæ and that of the blood corpuscles in different animals, an idea which, though correct in some reptiles, fails in others as well as in birds.

Bone is nourished by a plasma derived from the plexus of vessels ramifying on the lining membrane of the cancelli and Haversian canals. This, in its turn, is supplied by a special artery. Bone, indeed, may be regarded as mineral substance deposited between the meshes of vascular capillaries. The canaliculi and lacunæ, by presenting minute tubes with dilatations, present the best possible arrangement for the distribution of a nutritious fluid, which, from the slowness of its movement, will readily permit of mineral precipitation.

Bone also contains nerves, which accounts for the pain originating in them in cases of rheumatism, syphilis, malacosteon, and other diseases.

Chemical Composition of Bone.—Bone consists of an organic substance called bone cartilage or ossein, impregnated with earthy matter composed of various inorganic salts, the chief of which is tribasic calcium phosphate, calcium carbonate, and calcium fluoride. The earthy matter may be separated from the bone cartilage by macerating a bone for several days in dilute hydrochloric acid. The salts are gradually dissolved out, and the cartilage is left as a soft translucent mass, retaining the form of the bone. Another mode of analysing bone is to incinerate it till it becomes white. The organic matter is thus burnt off, and the ash may then be analysed. The composition of bone cartilage, according to Von Bibra* and Frémy,† is as follows :—

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.
From femur of ox .	50.13	7·07	18.45	24.35
From calf . . .	49.9	7.3	17.2	25.6
From rib of river carp	50.32	7.22	18.42	24.00

The following table shews the per centage of inorganic matter in human bones of various ages, according to Von Bibra.‡ It will be observed that the proportion of inorganic matter in bone is generally smaller in youth than in age :—

Name of Bone.	Per centage of Ash.	Name of Bone.	Per centage of Ash.
Male fœtus, 7mths.		*Woman*, 25 years	
Femur, tibia	59.1 to 59.6	Femur, tibia	68.4 to 68.8
Boy, 9 months		Humerus .	69.25
Femur . .	56.43	*Man*, 30 years	
Humerus .	58.58	Femur, tibia	68.0 to 69.4
Boy, 5 years		*Man*, 58 years	
Femur . .	67.80	Femur . .	68.53
Girl, 19 years		*Woman*, 78 years	
Femur . .	67.85	Femur . .	66.81

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* Von Bibra, *Op. Cit.*

† Frémy, *Ann. Chimie Phys.* [3] xlvii.

‡ Von Bibra, *Op. Cit.*

According to Frémy, the bones of all the mammalia shew the same average composition as those of man, but the bones of herbivorous animals generally contain a larger proportion of lime salts than those of flesh-eaters. The following table, modified from Frémy,* shews the comparative analyses of bones belonging to different orders of the animal kingdom :—

Name of Bone.	Ash per cent.	Phosphate of Calcium.	Phosphate of Magnesium.	Carbonate of Calcium.
Woman, 22 years, cranium	64.1	57.8	1.7	10.9
Man, 40 years, femur .	64.2	56.9	1.3	10.2
Egyptian mummy, femur .	65.0	58.7	1.7	5.9
Lioness, femur . .	64.7	60.0	1.5	6.3
Rabbit, femur . . .	66.3	58.7	1.1	6.3
Elephant	66.8	62.2	1.2	5.6
Horse, femur . . .	70.4	60.5	1.7	7.9
Ox, humerus . . .	70.4	61.4	1.7	8.6
Eagle	70.5	60.6	1.7	8.4
Chicken	68.2	64.4	1.1	5.6
Tortoise (carapace) . .	64.0	56.0	1.2	10.7
Carp	61.4	58.1	1.1	4.7

Transformation of Cartilage into Bone.—We have seen that near the osseous centre the cartilage cells are arranged in long groups or rows. This is especially observable in fœtal bone. (See Plate VI. figs. 11, 12, 13). It is between the groups of cells that we can see the mineral molecules of phosphate of lime deposited (Fig. 12, *b*, 13, *c*). These at length, by their aggregation, assume a linear arrangement, and form ridges of calcareous matter that extend between and surround the rows of cells, which now become first compressed together and then melt into one another, leaving open spaces (cancelli) or tubes (Haversian canals). The nuclei of these cells become embedded in the advancing ridges of bone, and form the lacunæ (Plate VI. fig. 12, *c*, *b*). Within the primary spaces and tubes so formed, however, the broken down cell walls form a secondary or hystolitic mass of molecules, from which new cells are formed that are developed into fibres and blood-vessels in the same manner that these structures are produced in the embryo. These ultimately constitute the living vascular membrane of the cancelli and tubes. As soon as a circulation of blood is established through them, nourishing matter is given off more regularly as from a centre, and thus the Haversian canals become surrounded by nucleated cells arranged in concentric series. As these become infiltrated with mineral matter, the nuclei are not invaded, but remain as open spaces or lacunæ, whilst between these and the limits of the cell walls, minute channels are left, which are the canaliculi. In the same manner, a regular deposition of phosphate of lime in a nucleated texture may produce bone in fibrous tissues—not cartilaginous—such as tendon, periosteum, the arachnoid membrane, &c., which structures it is by no means uncommon to find converted into bone.

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* Frémy, *Op. Cit.* Traité de chimie par Pelouze et Frémy, 2nd ed.

The regeneration of bone after fracture takes place in the consolidated clot or exudation which collects around the broken extremities. The blood corpuscles and serum are first absorbed, a fibro-cellular substance is formed resembling fibro cartilage, the cells arrange themselves in rows from the nearest ossifying centre, and phosphate of lime is precipitated between them, exactly as it is in fœtal cartilage, and so bone is produced. To this end the vascular apparatus, as furnishing this nutritive matter, must be regarded as all important. Every tissue in the neighbourhood capable of furnishing such necessary substance, assists in the formation of new bone, and not, as was formerly thought, only bone or only periosteum. It has been shewn by Ollier that so long as the tissue of bone retains its vitality, it may be removed from one animal to another, or transplanted to various parts in the same animal, and not only continue to live, but increase in bulk.

THE NERVE TUBES.—A nerve is made up of a greater or less number of minute tubes. These are composed externally of a delicate membrane, called the *neurilemma* of the nerve tube (Pl. V. fig. 16, *a*). Inside this is a transparent, semi-solid, and peculiarly plastic material, called the *white substance of Schwann*. This, in its turn, encloses a viscous fluid. On mechanically breaking up these tubes, the white substance of Schwann—which, in the fresh structure, is characterised optically by two distinct lines, with a clear central streak on each side of the tube—(Fig. 13, *a*) has the property of rolling itself into globules or corpuscles of varying size and shape (Fig. 17, *a*). Each of these is characterised by the double line externally, and I have frequently produced them by squeezing the white substance of Schwann out of the investing sheath or neurilemma, and have seen them under the microscope rapidly unite at their two extremities. By gently pressing these tubes also, when separated in a perfectly fresh nerve, the semi-fluid contents can be forced out of their extremities, and made to coagulate on the glass slide, outside the open mouth of the tube (Plate V. fig. 19, *a*). In the perfectly fresh tube I have never succeeded in seeing a central band or axis.

These tubes vary greatly in size, being largest in the cerebro-spinal nerves, generally reaching the one-thousandth of an inch in diameter (Fig. 13); they are smaller in the spinal cord (Fig. 14), and smallest in the white substance of the cerebral hemispheres (Fig. 18). In these two last situations, also, they present various enlargements, which I think are also post-mortem phenomena, the neurilemma being of exceeding tenuity, and easily stretched by the pressure of the covering glass when demonstrated under the microscope (Figs. 14, 17, 18). As they approach the periphery of the cerebrum and cerebellum, they become finer and finer, and are lost among the molecular grey substance in the one case, and the internal granular layer in the other. It has been supposed by several German anatomists that these nerve tubes are bound together by fibrous tissue. But careful examination has satisfied me that the supposed fibres are often minute tubes or the fibrillated substance of Schwann (Fig. 15). I have found, when a perfectly transverse section of the spinal cord is examined, in the carefully prepared specimens of Lockhart Clarke, with Ross's lens of the one-twelfth of an inch, that the tubes diminish in size until they resemble the smallest molecules; but when so minute as the sixteenth thousandth of an inch in diameter, I have distinctly seen the delicate external circle and central solid coagulated coloured rod (fig. 21). In the same manner, therefore, I believe, as histologists have hitherto failed to reach with their instruments the ultimate molecule in nutritive fluids, or the ultimate fibril in muscle, so they have not yet seen the ultimate tube in nervous matter.

Effects of reagents.—When any coagulating agent is added to the nerve tube—even water—the fluid contents are immediately solidified (Figs. 15, 20,) and, if long steeped in chromic acid, appear in the form of a solid rod, which runs down the centre of the tube. This is the *band of Remak*, or *axis cylinder of Purkinje.* It has, like the nuclear elements of the textures, peculiarly the property of being coloured by ammoniacal solutions of carmine, when it is easily shewn to be continuous with the contents of the nerve cell, and its course can be traced with great exactitude (Pl. III. fig.18, *d*,*e*,*b*). Coagulating agents also cause longitudinal fibrillation of the white substance of Schwann round the axis (Pl. V. fig. 15), forming concentric circles when viewed in tranverse section (Figs. 20, *b*, 21). The prepared specimens of Mr Lockhart Clarke have never been surpassed in beauty, and they have led, in his hands, to most important discoveries. At the same time, it is my belief, from prolonged careful investigation into the structure of the nerve tube, that, as no central axis can be demonstrated in the perfectly fresh tissue, its existence is altogether a post-mortem phenomenon.

Chemical composition of Nerve.—This department of physiological chemistry is still in obscurity. The reaction of living nerve is neutral, but after strong action, according to Funke, it becomes acid. White nervous matter, which is composed chiefly of nerve tubes, contains less water than the grey matter, but it contains more fat. The semi-fluid substance, forming the axis cylinder, is believed to belong to the same series of chemical compounds as fibrin and syntonin, and is probably united with oily matter. The substance constituting the medullary substance seems to be some sort of soluble albumin.

Functions of the Nerve Tube.—The nerve tube possesses the property of generating and conducting an influence in different directions on receiving impressions from various stimuli. The impressions may result from the contact of the physical agents producing light, sound, touch, sapid bodies, and odours. But there are, doubtless, numerous other tubes peculiarly qualified to receive other impressions which may give rise to peculiar sensations, such, for example, as those of cold or warmth, of weight, of hunger and thirst, and of numerous other feelings, which, although not yet actually discovered, must have relation to the special endowments of these tubes. It has been clearly determined that while the optic and auditory nerve tubes have the property of conducting the influences produced by special impressions, they have not the power of transmitting others. In the same manner with regard to the directions in which these influences travel, a particular nerve tube would appear to conduct only in one direction. The directions at present known are, 1st, from the brain to the voluntary muscular system generally ; 2d, from the surface and the external organs of sense to the brain ; 3d, from one side of the body to the other through the spinal cord ; 4, from the cerebro-spinal system through ganglia to numerous glands, non-voluntary muscles, the blood-vessels, and the tissues generally. There may be other directions through which nervous influence travels by special nerve tubes, but such have not yet been discovered. In the meantime, we know that the nerve tubes are not only idio-motor and sensitive (general and special), but diastaltic, secretory, nutritive, and vaso-motor, and that a nerve may be made up of one or more of these different kinds of tubes, and thus be simple or complex in its action. (See function of innervation.)

Evolution of Electricity in Nerves.—Du Bois-Reymond discovered that, like muscles, nerves possess an electrical current, but much weaker, running from the longitudinal external surface, which is positive, to the transverse internal one, which is negative. (See Animal Electricity.)

Effects of Electricity on Nerves.—Du Bois-Reymond has shewn that when a portion of nerve is traversed by a current of electricity, it is thrown into a peculiar state, called an *electrotonic state*, which will be fully described when treating of Animal Electricity. It has also been shewn that the further a motor nerve is irritated from the muscle the greater is its excitability and its influence on the muscle, which is the very contrary of what was formerly supposed to be the case. Other remarkable facts as to the excitability of nerves when stimulated by electricity, are the result of the incessant labours of the present Berlin school of physiology, with Du Bois-Reymond at its head. They are largely adding to our knowledge of the functions of the nervous system. As to the theories put forth concerning the nature of nervous action, it will for the present be sufficient to say, that they consist in attributing the changes which occur, to alterations in the position and forces of the ultimate molecules of the nerves. (See Animal Electricity).

These researches point out to us that the vital properties of nerves, as of other tissues, are correlative, and that excitability, like contractility, when employed, is at the expense of electricity. Hence the vast importance of temperature, moisture, the electrical condition of the atmosphere, and other general causes, to the integrity of the nervous system. The influence of electrical currents on nerves, also, when further studied, serves to explain numerous facts long recognised during storms, such as the restlessness of cattle, the so-called sportiveness of fish, increased irritability of insects, and even in man the rheumatic, neuralgic, cerebral, and other phenomena which occasionally then appear in nervous individuals. The excited or depressed condition of some persons in good or bad weather, may also be thus explained, and the whole inquiry lead to more exact and useful principles in the application of electricity, as a therapeutic agent.

GENERAL CONCLUSION AS TO THE MOLECULAR THEORY OF ORGANIZATION.

If now we take a general view of the structural relations of the tissues, we observe that the molecular, cellular, fibrous, and tubular elements, are more or less mingled together, but that some tissues abound in one, and others in another. Thus the molecular element abounds in the nutritive fluids, in voluntary muscle, and in the grey substance of the cerebral convolutions; the cellular element abounds in adipose, in glandular, and in epithelial tissues; the fibrous element in areolar texture, ligament, tendon, and muscular tissues; and the tubular element in brain, spinal cord, bone, tooth, and throughout the body in the form of minute ducts, nerves, and blood-vessels. They all, as we have seen, serve general purposes in the economy. The molecular may be regarded as nutritive, or, as Dr Beale has called it, germinal matter. The cells serve to elaborate this matter for secretion, excretion, and certain kinds of growth. The fibres connect parts together, and in the molecular form of muscular fibre, present the highest degree of contractility. The tubes conduct nutritive fluids, and the nerve tubes that influence which is capable of exciting action in brain, voluntary muscle, glands, and vessels, by bringing each in connection with one another, or under the control of mind.

We perceive further, that those actions which are peculiarly vital, such as growth in certain directions, the power of contractility, and the existence of sensibility, are not, as some have supposed, the peculiar attribute of any one peculiar element of the textures, such as of cells or nuclei. I regard one and all as possessing powers which are necessary for the wellbeing of the economy, and each as reacting for the common welfare on one another. Thus, growth may be molecular, cellular, fibrous, or tubular. Contractility and spontaneous movements may be present in each of these elements; and sensibility unquestionably is shared by nervous matter, at least in its molecular, cell, and tubular forms.

As to development, the molecular is the basis of all the tissues. The first step in the process of organic formation is the production of an organic fluid; the second, the precipitation in it of organic molecules, from which, according to the molecular law of growth, all other textures are derived, either directly or indirectly. (See p. 45.)

When we investigate the functions of plants and animals—for example, generation, nutrition, secretion, motion, and sensation, we find them all necessarily dependent on the permanent existence and constant formation of molecules. Thus generation, both in plants and animals, is accomplished by the union of certain molecular particles called the male and female elements of reproduction. Among the *Protophyta*, the conjugation of two cells enables their contents, or the *endochrome*, to mix together. This endochrome is a mass of coloured molecules, and the union of two such masses constitutes the essential part of the generative act. In the *Cryptogamia*, a vibratile antheroid particle, enters a germ cell, and finds this last filled with a mass of molecules which, on receiving the stimulus it imparts, assumes the power of growth. It is the same among the *Phanerogamia*, when the germ cell is impregnated by the pollen tube. In all these cases it is necessary to remember that the protoplasm is a mass of molecules; that a spore is another mass of molecules; that sporules are molecules; that antherozoids are only molecules with vibratile appendages; and that the so-called germinal matter of the ovule is also nothing but a mass of molecules. Cell forms are subsequent processes, and once produced may multiply endogenously, by gemmation, or cleavage. All that is here contended for is, that the primary form is *molecular*, and that the force-producing action in it is a *molecular* force.

In animals, as in vegetables, every primary act of generation is brought about by the agency of molecules. The *Protozoa* entirely consist of mere molecular gelatiniform masses, in which no cell wall or central cell exists. And yet such masses have the power of independent motion, and of multiplying by gemmation. Considerable discussion has occurred as to whether, among *Infusoria*, there is a union of sexes or a conjugation similar to what occurs among the *Protophyta;* but in either case it is by molecular fusion that the end is accomplished. In the higher classes of animals, there are male elements, consisting of molecules, generally with, but sometimes destitute of, vibratile filaments ; and female elements, composed of the yelk within the ovum, containing a germinal vesicle or included cell. Both spermatozoid and germinal vesicle, are dissolved in the molecules of the yelk, which then, either wholly or in part, by successive divisions and transformations, constitute a germinal mass out of which the embryo is formed. Here, as in plants, it is necessary to remember that the spermatozoids, the yelk, and the germinal mass, are all composed of molecules, and that these, combining together, form the nuclei, cells, fibres, and membranes, which build up the tissues and organs of the organism. It is not from either the male or the female element, that the embryo is formed. The supporters of an exclusive cell doctrine have endeavoured to shew that there is always a direct descent, either from the wall of the ovum, or from the germinal vesicle as its nucleus. Thus some consider that the vitelline membrane sends in partitions to divide the yelk mechanically. Others have formed the idea that the germinal vesicle bursts, and that its included granules constitute the germs of those cells which subsequently form in the germinal mass. Others, again, suppose that on impregnation, the germinal vesicle divides first, and that the molecules of the yelk are attracted round the two centres so formed. But numerous observations have satisfied me that both spermatozoid and germinal vesicles, are simply dissolved among the molecules of the yelk, from the substance of which, stimulated and modified by the mixture so occasioned, the embryo is formed—a view which has further the merit of explaining what is known of the qualities of both parents observable in the offspring. The truth appears to be, that in an analogous manner to that in which the pigment molecules of the skin are stimulated by the access of light to enter into certain vital combinations with one another, so the molecules of the yelk are stimulated by the access of the spermatozoid, to produce those other vital combinations that result in a new being. The essential action is not so much connected, as has hitherto been supposed, with the cell wall or nucleus, as with the molecular element of the ovum.

With regard to nutrition, food and all assimilable material must be reduced, in the first instance, to the molecular form ; while the fluid from which the blood is prepared—namely, chyle—is essentially molecular. Most of the secretions originate in the effusion of a fluid into the gland follicle, which becomes molecular, and gives rise to cell formation. In muscle, the power of contractility is inherently associated with the ultimate molecules of which the fasciculus is composed. And lastly, the grey matter of the sensory ganglia and of the brain, which furnish the conditions necessary for the exercise of sensation, and of even intellect itself, is associated with layers of molecules which are unquestionably active in producing the various modifications of nervous force. These molecules are constant and permanent as an integral part of these tissues, as much as cells or fibres are essential parts of others ; and their presence is not transitory, but essential to the functions of the organs to which they belong.

All morbid growths may easily be shewn to originate sometimes in a molecular blastema, at others in pre-existing cells. The coagulated exudation infiltrated into the lung, or on serous membranes, and from which pus and fibre cells originate, are excellent examples of the former, while the hypertrophy of glands and formation of certain cancerous and cancroid growths are good illustrations of the latter. In morbid alterations of texture, also, we shall have abundant opportunities of pointing out that the molecular law of development prevails, and that histogenetic and histolytic processes constitute the numerous alterations of texture constantly brought under the observation of the pathologist.

All these facts point to the conclusion that vital action, so far from being exclusively seated in the cells, is also intimately associated with the elementary molecules of the organism.

This molecular theory of organisation is opposed to the views of those who support an exclusive origin for the tissues in cells alone. The fallacy of such a cell theory will, however, be manifest by considering for a moment what it imposes upon us. Not the fact, which has been long recognised, that cell may be formed within cell, or that proliferation of cells constitutes an important and a common method of cell multiplication ; but *that in no other possible way* can a cell or a living particle be produced. It asserts that all embryonic textures in the ovum, all adult tissues during life, and every kind of morbid formation, are to be traced to the cell, and can originate in it alone. In short, parodying the celebrated saying of Harvey, "*omne animal ex ovo*," it has been attempted by Virchow to establish the law of "*omnis cellula e cellulâ*," and to maintain that "the cell is really the ultimate morphological element in which there is any manifestation of life, and that we must not transfer the seat of any real action to any point beyond the cell."* Now, such a doctrine is inconsistent with numerous facts, and we shall see that histologists (including Virchow himself) have been so unsuccessful in tracing all tissues back to cells, that they have universally recognised that cells must originate, in the first instance, from a formless or molecular fluid or material, called by Schwann a *blastema*. Besides, no attempt has been made (even by Virchow) to shew that muscle, nervous matter, the vascular system, and the blood only originate in cells. He himself admits† that this cannot be established, and describes white or areolar fibrous tissue as originating in intercellular substance, without the agency of cells at all.‡ Several tissues are absolutely structureless, such as the sarcolemma, the neurilemma of the nerve tube, the vitelline membrane, the anterior and posterior layers of the cornea, and the capsule of the crystalline lens. They are apparently the result of simple coagulation and the subsequent union of minute molecules such as occurs in the haptogen membrane. The blood of mammals is, for the most part, not cellular but nuclear, and we shall subsequently see that the nuclei in the adult are more probably the result of molecular than of cell formation. The development of bone, and the various forms mineral matter assumes in the integumentary skeletons of many animals, such as the *Holothuria*, *Sinaptæ*, &c., are wholly opposed to this cell theory, the mineral matter being deposited outside the cells, and often assuming the form of spicules, hooks, anchors, &c., which can have no possible reference to cell growth. Then, so far from it being correct, "that we must not transfer the seat of real action to any point beyond the cell," which is another fundamental part of this cell theory, Virchow admits§ that the contractile action of a muscle is seated *in its ultimate granules;* and he adopts* Du Bois-Reymond's theory of electrical action in nerve as being dependent on "a change in the position which *the individual molecules assume to one another.*" If therefore, it cannot be shewn by the chief supporter of this theory, that many important tissues are formed directly from cells, and if it be admitted that the vital actions of these same tissues are inherent in their ultimate molecules—elements in no way connected with, and quite distinct from cells,—what becomes of the formula, "*omnis cellula e cellulâ,*" and of the doctrine that "we must not transfer the seat of real action to any point beyond the cell?"

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* Cellular Pathology, by Chance, p. 3. † Ibid. p. 50. ‡ Ibid. p. 44. § Ibid. p. 54.

On the other hand, the molecular theory of organisation does not appear to me chargeable with any such defects. It is consistent as a whole, and embraces all known facts. As investigations are multiplied, the more it becomes evident that the ultimate vital elements of the tissues are their molecular, and not their cell, constituents. Indeed, it is now agreed by many upholders of a cell theory, that the potential part of the cell is not the wall nor the nucleus, but the contents. Now these contents are for the most part molecular; and if we must have a doctrine of unities, it is evidently more reasonable to adopt a view of simple unities like molecules, than of composite advanced formations like cells. As a whole, the molecular theory appears to me to possess all the attributes of a true theory, and as such it constitutes not only a basis on which the formation of healthy structures may be explained, but is one eminently valuable when applied to morbid formations, and, above all, in assisting us to reach correct modes of treating disease and a true therapeutics.

From what has been said, it will be apparent that it has not been my object, in directing attention to a molecular theory of organisation, to interfere in any way with the well-observed facts on which physiologists have based what has been called the cell theory of growth. True, this last will require modification in so far as unknown processes of growth have been hypothetically ascribed to the direct metamorphosis of cell elements. But a cell, once formed, may produce other cells by buds, by division, or by proliferation, without a new act of generation, in the same manner as many plants and animals do, and this fact comprehends most of the admitted observations, having reference to the cell doctrine. The molecular, therefore, is in no way opposed to a true cell theory of growth, but constitutes a wider generalisation, and a broader basis for its operations. It is not a fortuitous concourse of molecules that can give rise to a plant or animal, but only such a molecular mass as is formed from organic matter and receives appropriate stimuli, to act in certain directions.

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* Cellular Pathology, by Chance, p. 290.

These views, originally put forth by the author in 1855, are supported by a multitude of facts and observations accumulated by histologists in past and present times. Many of them, it is true, employ different expressions in referring to the primitive molecular material from which organisation proceeds: thus, it is the "*organised concrete*" of Haller; the "*solidescible nutritive fluid*" of Wolf; the "*primordial mucous layer*" of Burdach; the "*sarcode of Dujardin; the blastema*" of Schleiden and Schwann; the "*proligerous pellicle*" of Pouchet; the "*germinal matter*" of Beale; the "*protoplasm*" of Remak, Von Mohl, and Kühne; the "*embryo-plastic matter*" of Robin; the "*primordial protogenes*" of Haeckel, &c., &c., all of which terms express essentially the same thing. The researches of Robin, Onimus, and others in France, and the recent investigations of Chauveau* and Burdon Sanderson,† which prove that the active powers of contagia are seated in the molecules (called *Microzymes* by Béchamp), and not in the cells nor fluids of infecting matters, may also be referred to as giving this doctrine unequivocal support.

The molecular theory of organisation must ultimately constitute the basis for the arts of horticulture, agriculture, and medicine. Thus vegetables and animals grow by the juxtaposition of molecules, which are introduced into the economy in a fluid holding in solution the particles of which the different textures consist. These are deposited, and so increase of bulk takes place. Any interruption to this process, or any violent disturbance in their statical, chemical, or dynamical arrangements when formed, is the fruitful cause of disease. If this occurs in nervous matter, it causes mental aberration or pain; if in muscle, spasm or paralysis; if in the blood, alterations in growth, secretion, excretion, &c. In cases of faulty nutrition, it is reasonable to conclude, that if we could add to, or subtract from, the particular molecular elèments which are essential to that process, we could accelerate or retard it : and this is within the reach of the medical practitioner. For example, codliver oil in scrofulous and phthisical cases operates, not because of any vague specific virtue it has been supposed to possess, but on account of its power of adding to the molecular constitution of the chyle, and thus favouring the building-up function of the blood and tissues. There can be no doubt that iron, lead, opium, strychnine, and other of our remedial agents, must operate on this or that tissue in virtue of the affinities between them and the ultimate molecules of such textures. Again, the law of successive molecular evolutions and disintegrations, to which I have directed attention, points out that in the chain of processes, each step is dependent on the one that precedes it ; and that inasmuch as regards form we cannot go farther back than the molecular form, so a knowledge of it and the manner in which it is produced from fluids holding proximate principles in solution, is not only the first step to an acquaintance with organisation, but is the one which should best inform us how to repair that organisation, when so altered as to constitute disease.

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* Comptes Rendus. Tom. LXVIII. p. 289.

† Twelfth Report of the Medical Officer of the Privy Council. 1870.

THE PHYSICAL AND VITAL PROPERTIES OF THE TISSUES.

The living body possesses certain properties which are either *physical* or *vital.* By the term *property* is understood the mode in which any body manifests itself to our senses. Physical properties are those which the body possesses in common with other masses of matter. Vital properties, on the other hand, are peculiar to living beings. They are called *vital* because they cannot be accounted for or explained by any known physical laws, and are believed to obey only such as operate in living organisms. As our acquaintance with the phenomena manifested in living beings has advanced, many of them, which were at one time supposed to be vital, have been brought into the domain of physics ; and it is highly probable that some of those phenomena which are at present denominated vital, because we cannot offer any explanation of them, may ultimately be found also to obey physical laws. For this reason, it is now admitted that a knowledge of physics, as applied to physiology, is of the highest importance ; and it is, therefore, our aim, in what follows, to place before the student a condensed statement of those facts in physics which are illustrated by, and throw light upon, many physiological phenomena.

I. THE PHYSICAL PROPERTIES OF THE TISSUES.

These may be described under the following heads : 1st, General properties, such as gravity, divisibility, porosity, compressibility, and elasticity ; 2d, Molecular properties, including cohesion, adhesion, and affinity ; 3d, Mechanical properties, such as density, weight, the properties of the lever, and the properties of the pulley ; 4th, Hydrostatic and hydrodynamic properties, or the physical properties of the animal fluids ; 5th, Pneumatic properties, or the physical properties of the gases of the body, including a consideration of atmospheric phenomena in relation to physiological action; 6th, Properties relating to heat ; 7th, Properties relating to acoustics ; 8th, Properties relating to optics ; 9th, Properties relating to magnetism ; and 10th, Properties relating to electricity, or animal electricity.

1. General Properties.—The general properties of the body are those which it possesses in common with all other bodies ; and they include gravity, divisibility, porosity, compressibility, and elasticity.

a. Gravity.—According to the law of gravity, every body is attracted towards the centre of the earth with a certain determinate force. This force is the resultant of a number of parallel attracting forces, and is equal to, or represents, the weight of the whole body. In whatever position the body may be placed, the resultant always passes through a particular point in it, termed the *centre of gravity.* When one point of a body is fixed, it is said to be *in equilibrium,* if a vertical line drawn from its centre of gravity passes through that fixed point, and if the body is supported at different points, it is in equilibrium when a vertical line drawn through its centre of gravity passes within the geometrical figure formed by joining the lines of support.

In proportion to the smallness of the area of the supporting base, is the difficulty in maintaining equilibrium, and thus it is more difficult to stand upon one leg than upon two. The gymnast, by moving his body from side to side, and skilfully using his balance-pole, maintains his equilibrium upon the tight-rope, by carefully keeping the centre of gravity of his body vertically over the narrow area of the rope. The human body is, upon the whole, symmetrical, and if it were perfectly so, the centre of gravity would be in the medium line ; but the presence of a-symmetrical organs, such as the liver, spleen, and pancreas renders the two halves of the body slightly unequal. When a healthy adult is lying in the horizontal position, the centre of gravity will be found in a plane transversely cut through the last lumbar vertebra. In the new-born infant, it is somewhat higher. But if a man stands erect, a line leading through the centre of gravity of his body will pass through the area included between the soles of the feet, as in Plate IX. fig. 2, where G is the centre of gravity, and G, G^1 the line of gravity. If he has a burden on his back, Plate IX. fig. 2, this burden, having the line of gravity S, S^1, the line of gravity common to both will be g, g^1, passing behind his feet, and the man will be in danger of falling backwards. To avoid this, he bends forwards, as in Plate IX. fig. 1, and thus brings the common centre of gravity, g, g^1, farther forwards, and within the area of the soles of the feet. In the same manner, women advanced in pregnancy bend backwards because the abdomen contains the enlarged uterus enclosing the fœtus and the membranes of the ovum, forming in all a weight of about 11 lbs. The same laws explain the reason why a man stoops forward while he ascends a hill, and extends the trunk and bends backwards while he descends. Again, we observe the influence of gravity in the accidental engorgement of the blood in the veins of the inferior extremities ; in the disappearance of this engorgement on placing the limb in an elevated position ; in the redness and turgescence of the face when the head is kept lower than the trunk ; in the tumefaction which occurs in the back or sides in cases of ascites from *decubitus* ; in the syncope which occurs in a feeble person on sitting or standing up, and which is removed by a horizontal position, &c.

b. Divisibility.—By divisibility is meant that property of matter by virtue of which it may be divided into numerous distinct parts. Every drop of human blood contains many thousands of blood corpuscles, each about the 1.3000th of an inch in diameter. Many of the *Bacteria* observed on the scum which forms, after some hours, on an infusion of hay and straw, are only about 1.150,000th of an inch in diameter (see p. 46). The 1.100th of a grain of strychnia, will kill an adult rabbit ; and as this is diffused through the blood, it is almost impossible to conceive the minuteness of the particles into which it is divided. One drop of vaccine virus, diffused in an ounce of powdered sugar, has communicated cow-pox to an individual, from the smallest particle of the powder coming in contact with the blood. It is highly probable, however, from recent investigations and calculations by Professor Sir William Thomson,* that there is a limit to the divisibility of matter, when we reach ultimate indivisible particles, termed *atoms.*

c. Porosity.—The molecules of matter are not in actual contact. Spaces, or interstices, exist between them, termed *pores.* In 1661, the Florentine academicians proved the existence of pores, even in so dense a body as gold ; and at the building of the Britannia bridge, it was also found that the water used in the powerful hydraulic presses employed to raise the tube, was freely forced through the pores of the thick iron cylinders of the press. These pores are of two kinds, *physical* and *sensible.* Physical pores are very minute, sensible pores are usually apparent, either to the naked eye or to the microscope. All organic bodies are porous, and the pores may be occupied by fluids or gases. Dry hairs, when moistened, increase in diameter, and diminish in length, in consequence of the passage of fluids into the pores.

d. Compressibility.—This is the property in virtue of which the volume of a body is diminished by pressure, inasmuch as its constituent molecules are brought closer together. Gases are more compressible than fluids, fluids than solids, and by regulating the amount of the pressure, matter may exist in either of these three physical conditions. The various tissues are all more or less compressible. A man is shorter at night than he was in the morning, or after a long journey on foot, from the weight of the head and trunk, compressing the intervertebral cartilages.

e. Elasticity.—Elasticity is the property by means of which a body resumes its original form, when the external force which altered that form ceases to act. A ball of ivory, a steel spring, a caoutchouc bag, and a piece of artery, are all highly elastic bodies. All liquids and gases are perfectly elastic, but there is a limit to the elasticity of solids, beyond which they are either incapable of regaining their original size, or they break. The animal body affords numerous examples of elasticity. We find a highly elastic tissue in the *ligamentum nuchæ*, in the *ligamenta subflava*, and in costal cartilage. The coats of the larger arteries are easily extended, and after the removal of the dilating force, they quickly return to their former condition. Many organs perform their functions almost entirely through the agency of elasticity—destroy it, and the function is abolished. For example, in emphysema of the lungs, expiration becomes difficult, and at length impossible, so that death occurs from these organs ceasing to be elastic. Rigidity of the arteries, from deposition in their coats of mineral matter, by which they lose much of their elastic power, is a common cause of apoplexy. The walls will not yield to the mechanical force of the heart; they give way, and extravasation of blood into important textures is the result.

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* Sir William Thomson. *Nature.* 1870.

2. MOLECULAR PROPERTIES.—A molecule in physics is a hypothetical particle which is made up of an aggregation of smaller hypothetical atoms of matter. Two forces are ever acting upon these molecules, the one force, termed *molecular attraction*, which manifests itself in various ways, and is designated by the terms cohesion, affinity, or adhesion; the other, *molecular repulsion*, will be referred to afterwards when describing the properties relating to heat.

a. Cohesion is the force which unites two molecules of any body, and it is usually expressed by the weight which suffices to separate these molecules from each other. A thin iron wire, the transverse section of which is about the 3.1000ths of a square inch, will support a weight of 330 lbs. No part of the animal body has so strong a cohesive power as thin iron wire, but by special combinations of textures, the cohesive power of which may vary considerably, those parts of the body which have to sustain a great weight, or be subjected to considerable tension, are constructed of such a strength that their cohesion is far beyond their most ordinary requirements. According to

Valentin,* it would require a weight of 880 lbs., or about seven times the weight of the whole body, to tear the extensor tendons of the foot.

b. Affinity.—This force is usually termed chemical attraction or affinity. It unites the elements into compound bodies. It is a force of intense energy, is most strongly exerted between dissimilar substances, producing a third substance entirely different in properties from either of the components, and under its influence, the elementary bodies, comparatively few in number, arrange themselves into all the various forms of matter found in the three kingdoms of nature.†

c. Adhesion.—This force is exerted between the superficial molecules of bodies in contact. It produces the phenomena of *friction.* When two surfaces of any body are pressed together, the superficial molecules interpenetrate, and there is a loss of molecular force, and development of heat. Friction forms an obstacle to movement, but it favours stability. The movements of the abdominal and thoracic viscera, of the joints and tendons, are all accompanied by friction. A loss of power is the result, but this is reduced to a minimum, by the contiguous surfaces being constantly lubricated with fluids, such as the fluid in the various serous sacs and *bursæ mucosæ*, and the synovia of joints.

Molecular forces are constantly operating in all living textures, and have been previously referred to when speaking of molecular coalescence and disintegration (p. 40).

3. MECHANICAL PROPERTIES.—The tissues possess certain properties which obey the laws of mechanics. These may be considered under the heads of density, weight, the properties of the lever and the properties of the pulley.

a. Density.—By density is meant the quantity of matter contained in a certain volume. Certain tissues of the body are more dense than others. Bone is more dense than muscle, enamel than bone. An organ may be more dense in one part than in another, as, for example, the crystalline lens is more dense in the centre than at the periphery.

b. Weight.—Weight may be of three kinds, absolute, relative, and specific. *Absolute* weight is the pressure exerted by a quiescent body upon the surface on which it rests, and is the result of the action of gravity. A book lying on a table, presses on the table with a certain weight proportional to its mass. *Relative* weight is the ratio of the absolute weight of a body to that of another body arbitrarily chosen. It is determined by means of the balance, and the unit of weight now employed by scientific men, is that of a *gramme*, according to the French metrical system of weights and measures.* *Specific* weight is the ratio of the weight of a certain volume to that of an equal volume of distilled water, at 4°C. In other words, it is *specific gravity.*

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* Valentin, Physiology. Translated by Brinton. London, 1853, p. 20.

† Miller's Elements of Chemistry. Part I. Chemical Physics. London, 1867.

The weight of the human body varies much in different individuals. The following table, prepared from the statistics given by J. W. Danson†, from observations upon 4,800 criminals at all ages, shews the weight of the human body up to 30 years, and, in a parallel column, the average height of the individuals :—

AGE.	WEIGHT.						HEIGHT.	
	Average.		Maximum.		Minimum.		Average.	
	Stones.	*Pounds.*	*Stones.*	*Pounds.*	*Stones.*	*Pounds.*	*Feet.*	*Inches.*
18	8	10.79	10	13	6	6	5	4.34
19	9	4.11	12	8	7	4	5	4.94
20	9	5.58	12	8	7	13	5	5.11
21	9	5.02	12	0	7	3	5	5.57
22	9	12.41	13	2	7	0	5	6.17
23	10	2.95	12	12	7	12	5	6.17
24	10	2.0	12	12	7	12	5	5.94
25	10	5.65	13	8	8	2	5	6.30
26	10	1.06	13	8	6	12	5	6.28
27	10	4.75	13	10	7	12	5	6.38
28	10	2.62	13	2	7	7	5	6.65
29	10	5.53	13	12	8	4	5	7.02
30	10	1.55	14	1	8	1	5	6.36

According to Valentin‡ the weight of the new-born infant is from 6.62 to 6.84 lbs. The weight increases up to the fortieth year in the male, and the fiftieth in the female; and both then weigh about twenty times the weight of the new-born infant.

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* For a clear and concise account of the French metrical system, see Hoffman's Lectures on Chemistry. London.

† J. W. Danson. *Statistical Society's Journal,* March 1862.

‡ *Op. Cit.*

The weight of the various organs also varies much in different individuals. The following are averages:—*

Organ.	*Weight.*
Heart,—adult male,	11 oz.
adult female,	9 oz.
Brain,—adult male,	$49\frac{1}{2}$ oz.
adult female,	44 oz.
Spinal cord,	1 oz. to $1\frac{3}{4}$ oz.
Liver,	50 oz. to 60 oz.
Pancreas,	$2\frac{1}{4}$ oz. to $3\frac{1}{2}$ oz.
Spleen,	5 oz. to 7 oz.
Lungs,—adult male,	45 oz.
adult female,	32 oz.
Thyroid,	1 oz. to 2 oz.
Thymus, at birth,	$\frac{1}{2}$ oz.
Kidney,	$4\frac{1}{2}$ oz.
Suprarenal capsules,	2 drachms.
Prostate,	6 drachms.
Testes,	$\frac{3}{4}$ oz. to 1 oz.
Unimpregnated uterus,	7 to 12 drachms.

c. *The properties of the lever.*—A lever is a straight, solid, rigid bar turning on an axis. The axis is the *fulcrum*, and the parts of the bar on each side of the axis are the *arms* of the lever. Levers are of three kinds, according to the position of the fulcrum with reference to the power and the resistance. If the fulcrum be between the power and the resistance, the lever is of the first kind (Pl. VIII. fig. 3); if the resistance be between the fulcrum and the power, the lever is of the second kind (Pl. VIII. fig. 5); and if the power be between the fulcrum and the resistance, the lever is of the third kind (Pl. VIII. fig. 4). A balance is an example of the first kind of lever; a wheel-barrow of the second; and the treadle of a turning lathe of the third. An example in the human body of a lever of the first order is seen on rising on tip-toe, when the ankle is the fulcrum, the *Tendo-Achilles* the power, and the ground the resistance (Pl. VIII. fig. 7). The skull in its movements upon the atlas is also an example of the first order of lever. The second order of lever is exemplified in opening the mouth by the action of the anterior belly of the digastric muscle, which is the power, the temporo-maxillary articulation being the fulcrum, and the resistance the temporal muscle (Pl. VIII. fig. 6). The most striking examples of the third order of lever are to be met with in the animal economy. The limbs of animals are levers of this kind. The weight of the limb is the resistance; a strong muscle, capable of very powerful contractions through very short spaces, attached to the bone near the joint, is the power; and the socket of the bone is the fulcrum. At the shoulder joint, the glenoid cavity of the scapula is the fulcrum, the deltoid inserted into the humerus is the power, and the weight of the upper extremity is the resistance. At the elbow joint, the fulcrum is the articular surface on the lower end of the humerus, the power is the biceps inserted into the tubercle of the radius, and the resistance is the fore arm (Pl. VIII. fig. 8). In each of these cases, a powerful contraction of the muscle, acting through a short space, gives considerable motion to the limb; but there is a loss of muscular force, because the power acts on the short, while the resistance acts on the long, arm of the lever. In levers of the third order, therefore, the power must always be greater than the resistance. For example, the biceps is inserted into the radius at a distance of $2\frac{1}{10}$ inches from the elbow joint, while the centre of the palm of the hand is 13 inches from the same axis. Hence, if, as in Pl. VIII. fig. 8, a weight is placed on the palm of the hand held horizontally, the force, P, exerted by the muscle, is expressed by the ratio :—Power : Weight : : 13 : $2\frac{1}{10}$; or, $P = W \times \frac{130}{21} = 6\ W$ nearly: so that to support a weight of 1 lb. in the hand, a force equal to 6 lb. must be exerted by the muscle.*

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* Quain's Anatomy. 7th edition. London.

d. The properties of the Pulley.—An ordinary simple pulley consists of a rope passed over a wheel. The efficiency of the arrangement depends on the rope, not on the wheel, the latter being introduced for the purpose of diminishing friction and the imperfect flexibility of the rope. The pulley is a mechanical contrivance for applying power in a direction in which it may be exerted to advantage. An example of the application of the pulley in the human body is seen in the case of the tendon of the superior oblique muscle of the eyeball, which passes through a fibro-cartilaginous ring or pulley attached to the *fovea trochlearis* of the frontal bone. It is also seen in the case of the tendon of the *circumflexus palati* which winds round the hamular process of the sphenoid bone.

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* Rev. S. Haughton, M.D., F.R.S., "Natural Philosophy." London. P. 20.

4. HYDROSTATIC AND HYDRODYNAMIC PROPERTIES.—A knowledge of the laws regulating the behaviour of liquids at rest or in motion, is of great importance to the physiologist.

Liquidity.—An essential peculiarity of liquids is the great mobility of their particles. The slightest force displaces the molecules of a liquid. This peculiarity is termed *fluidity* or *liquidity*, and it is owing to this property that a liquid assumes the shape of any vessel into which it may be placed. Liquids have been proved, by direct experiments made by Canton, Perkins, Oersted, and more recently by Colladon and Sturm,* to be compressible to a very minute extent. Under atmospheric pressure water is compressed 0.00005 of its bulk. The same experiments proved that liquids are perfectly elastic. As a rule, the densest liquids are those which yield least to compression.

Pressure of liquids.—When pressure is made upon a liquid at one point, the force propagates itself equally in all directions. This is called *Pascal's principle of equality of pressure.* In accordance with this law, every portion of the sides of a vessel containing fluid is exposed to a pressure, corresponding to the weight of the fluid pressing against it. In the vessel of water ACD, Plate VIII., fig. 9, a particle of the fluid at B is pressed downwards by the column of water AB, and upwards by an equal force, and this pressure is communicated laterally to the particles lying in the horizontal plane BD and BC. Thus every point in the sides of the vessel bears a pressure of the same amount as that which acts on the particles of fluid in the horizontal layer. The lateral pressure of a fluid on any area of the inner surface of the vessel is proportional to the depth of that area below the surface of the fluid. This will be evident on looking at Fig. 10 in Plate VIII. In the vessel EH, the fluid column AC transmits its pressure through the layer CD to D; and the column EF transmits its force to G; the pressure at G must therefore be greater than the pressure at D in the same proportion as EF is greater than AC.† The pressure of a fluid, however, depends not merely on the height of the column, but also on the specific gravity of the fluid. A fluid, the specific gravity of which is four times that of another fluid, will exert a pressure four times as great.

The walls of the arteries are always subjected to a certain amount of pressure or tension. By means of an instrument termed the *hæmadynamometer* or *kymographion*, the principle of which is Pascal's law just described, this pressure or tension, or in other words, the strength of the current of the blood, may be accurately measured. This instrument will be fully described in treating of the Practical Physiology of the circulation. The average amount of pressure in the arteries of the larger mammalia amounts to from 5·9 to 6·3 inches of mercury. (See Circulation.)

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* Colladon and Sturm, *Ann. de Chimie,* II. xxxvi.

† Golding Bird and Brook's Elements of Natural Philosophy, London.

Hydrostatic equilibrium.—Water permitted to flow through a series of tubes from a cistern will always tend to rise to the level of the fluid in the cistern. It will do so independently of the calibre and form of the tubes. Let LU in Fig. 17, Plate VIII., be a common reservoir, having inserted in it the differently shaped tubes A B C D E F, and water be poured into D, it will attain the same elevation in each of the tubes, and it will remain in a state of hydrostatic equilibrium.

Principle of Archimedes.—When a body is floating in a fluid, it displaces a certain amount of liquid, and it is subjected to two forces, its own weight and the resultant of the fluid pressures acting vertically upwards through the centre of gravity of the displaced fluid. It will be upheld by a force equal to the weight of the liquid displaced by the body. This is called the principle of Archimedes. The human body is on the whole lighter than an equal volume of water, and if quiescent floats on the surface.

Specific gravity.—Specific gravity is relative weight, and the standard of comparison is the weight of the same volume of distilled water at 4°C. The specific gravity of the various constituents of the body varies within narrow limits. Of all the animal textures, fat possesses the lowest specific gravity, bones the highest. None of the fluids have the specific gravity of water, because they all contain solid matters dissolved. The fluid of lowest specific gravity found in the body is the aqueous humour of the eye. The following is a list of the specific gravities of the more important solids and fluids, according to Valentin: *

Substance.	Specific gravity.
Water,	1000
Blood,	1060
Urine,	1020

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* Valentin, *Op. Cit.*

Substance.	Specific gravity.
Liquor Amnii,	1004 to 1020
Saliva,	
Gastric Juice,	
Bile,	1020 to 1040
Lymph,	
Milk,	
Brain,	1009 to 1030
Tendons,	1110
Cartilages,	1100
Fresh Bones,	1200
Muscles,	1020

Capillarity or imbibition.—The physical phenomenon of capillarity, or the rise of fluids in fine tubes, is manifested when a tube or rod having a very small diameter is placed in contact with a liquid. When a glass tube, bent as in fig. 13, Plate VIII., is filled with water, the liquid settles into a position of equilibrium, in which the water at A and B is raised upwards against the sides of the tube, so that the surface is concave. But if the same glass tube is filled with mercury, it is not moistened by the mercury, and the mercury, after coming to equilibrium at A and B (Plate VIII. fig. 12), is depressed against the sides of the glass tube, so that its surface is convex. The smaller the diameter of the tube the more apparent are these phenomena. Similar results are observed when two parallel glass plates are brought sufficiently near each other in a fluid. By means of capillarity, water rises in the pores of wood, sponge, &c., and thus becomes diffused throughout the texture. Tendon, membrane, or cartilage will dry into a solid brittle mass unlike anything which occurs in the body, but plunge them into water, and they imbibe moisture, and again become soft, elastic, and resume their original properties. Keeping the tissues moist by means of imbibition, is of immense importance in the animal economy.

Endosmose.—When two liquids of different densities are separated from each other by a thin membrane or porous partition, a current sets in from each liquid to the other, and these currents continue till the two fluids become of the same density. Over one end of a long glass tube (Plate VIII. fig. 14) tie firmly a piece of membrane (A), such as bladder, and fill the tube with a strong solution of sugar. Then immerse this end of the tube in a vessel of pure water (Plate VIII. fig. 15 C). It will soon be found that the fluid begins rapidly to ascend in the tube, and the surrounding water to acquire a sweet taste. Such an instrument is called an *osmometer*. Two currents have been established, the one termed the *endosmotic current* (ἔνδον, inwards, ὠδμος, impulse), flowing from the water into the syrup, and the other, termed the *exosmotic* (ἔξ, outwards), flowing from the syrup to the water. The sugar solution being much more dense than the surrounding water, more water passes into the syrup than syrup into the water. To produce osmose, it is necessary that the fluids be different but capable of mixing, that the densities be different, and that the septum between them be permeable and more freely wetted by one liquid than the other. The liquid which most freely wets the membrane passes out more rapidly than the other passes in. As a general rule, endosmose takes place towards the denser liquid. If a film of collodion forms the septum, with alcohol on one side of it and water on the other, the alcohol will pass towards the water, because the collodion film is more easily wetted by the alcohol.

The investigations of Graham* have led to the following conclusions: 1. Urea, gum, sugar of milk, gelatin, and other neutral organic substances, exercise almost no osmotic action; 2. Neutral salts, such as sulphate of magnesia, have no special osmotic action; 3. Alkaline solutions produce endosmotic action to a very remarkable extent. When the alkaline solution was placed in the osmometer, a large bulk of water soon entered the osmometer, while only a small portion of the alkaline salt escaped into the water; 4. Dilute acids and solutions of acid salts produced a current in the opposite direction, that is, they passed readily from the osmometer to the surrounding water; 5. In every instance the osmosis seemed to depend on a chemical action on the septum.

Endosmose is seen to take place in the highest degree between gases; and it has been found that the force of diffusion between two gases separated by a septum is inversely as the square roots of their densities. The absorption of fluid by cutaneous surfaces deprived of epidermis, and by mucous and serous membranes are all to be explained by endosmose. A fluid, such as water, having a lower specific gravity than the blood, is rapidly absorbed by the blood vessels of the mucous membrane of the stomach and intestines. The action of certain purgatives, such as solution of the sulphate of magnesia, is also partly explained by endosmotic action. In this instance, the saline solution in the bowel, having a higher specific gravity than the blood, the serum of the blood transudes from the vessel into the bowel. By the researches of Matteucci, it has been shewn that the absorption of fatty matter by the lacteals in the villi of the intestine is also due to osmose. Fatty substances do not moisten the surfaces of membranes, and therefore are not absorbed; but when made into an emulsion by the action of an alkali, they are absorbed readily. (See Chylification.)

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* Graham, *Phil. Trans.* 1854.

Endosmotic action is greatly influenced by the movement of one of the fluids. An arrangement is shewn in Fig. 15, Plate VIII., which illustrates this fact very clearly.* Let *b* be a funnel, having attached to it a piece of blood vessel or intestine, immersed in a fluid in the vessel *d*. To the other end of *a* is the bent glass tube *c* dipping into another vessel *e*. If we now allow a fluid continually to flow towards *e*, while the fluid in *d* is at rest, fresh particles of the fluid in *a* are brought into contact at every instant with *d*. Thus the difference in density between fluid in *a* and the fluid in *d* will be kept up for a long time, and the endosmotic action is increased. This experiment shews that the movement of the chyme in the intestines, and of the blood in the vessels, influences osmotic action to a considerable extent.

Dialysis.—According to Graham,† all bodies may be referred to one or other of two great classes, which he terms *crystalloids* and *colloids*. The *crystalloids* have a crystalline structure, a sapid taste, form solutions free from viscosity, and have a very strong tendency to diffusion through a porous septum; while the *colloids* (from κόλλη, glue) have a jelly-like consistence, no taste, and diffuse through a porous septum with great difficulty. Colloids, according to Graham, are very liable to change, and colloidal matter is matter in a dynamical condition. All crystalline substances are examples of crystalloids; gum, starch, dextrin, tannin, gelatin, and albumin, &c., are examples of colloids. By the process called *dialysis* (διὰ, asunder, λύσις, separation) these two classes of substances may be separated from each other. A *dialyser* consists of a shallow tray, made by stretching a sheet of parchment paper over one side of a hoop of glass or gutta-percha; place the mixture for experiment in the tray, and then float the apparatus in a vessel of pure water. The crystalloids will gradually diffuse out into the water, while the colloids remain in the dialyser. The importance of the process of osmose and dialysis in a living being must be obvious, especially as regards nutrition, absorption, exhalation, and excretion.

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* Valentin, *Op. Cit.* p. 50.

† Graham, *Phil. Trans.* 1861–2.

Fluids in motion.—a. Velocity of efflux.—If the vessel *a d* in Plate VIII. fig. 11. be kept constantly filled with water up to the level *e f*, while it is allowed to discharge itself by the orifice *h*, the velocity of efflux is the same as that of a body falling from a height *g h*. The distance *g h* forms the space through which the molecule of water falls. Now, if the level of the liquid be allowed to fall to *l n*, the velocity of efflux will be the same as that of a body falling through the space *n h*. This law was discovered by Torricelli. It is thus the degree of pressure, *g h* or *n h*, which determines the velocity of efflux. This velocity is termed the *theoretical velocity*, as distinguished from the *actual velocity*, which is conditioned by the form of the aperture in the bottom of the vessel, the diameter and course of the tubes through which the fluid is driven, and the amount of resistance offered by bodies which the fluid may meet with on its way. Usually the actual velocity is about 62 per cent. of the theoretical velocity. When a stream of urine is expelled from the bladder by the urethra, it is discharged with less force than that which the muscular walls of the bladder, assisted by the abdominal muscles, impress upon it. The resistance of the atmosphere at the opening of the urethra, and the friction of the fluid against its sides, diminish the velocity of the efflux.

b. Discharge of fluid through tubes.—In the preceding paragraph, we have supposed the fluid to flow directly from a small aperture in the bottom of the vessel. But if a long tube is fitted to the aperture, the friction of the fluid upon the sides of the tube comes into play. M. Poiseuille* has studied the discharge of liquids through small tubes by the simple apparatus seen in Pl. VIII. fig. 16. It consists of a glass bulb, the volume of which, in cubic inches, between the marks M N, has been ascertained. It is furnished with a capillary tube, A B, the length and diameter of which are also known. Water, or the liquid to be experimented on, is now sucked up through the tube A B till it reaches the level M, and the whole apparatus is connected above with a vessel containing compressed air, by means of which a uniform pressure may be obtained. The pressure of the air drives the liquid before it through the tube A B, and the

* Poiseuille, *Ann. de Chimie,* III. xxi. 76

time occupied in the change of level from M to N is noted. The results of these experiments are as follows* :—1. The flow increases directly as the pressure. 2. With tubes of equal diameter, and under equal pressures, the quantities discharged are inversely as the length of the tube. 3. In tubes of equal lengths, but of different diameters, the flow is as the 4th-powers of the diameters : for example, if tubes, one of 0·4 millimetre, another of 0·2 millimetre in diameter, be compared together, the efflux from the larger tube would be sixteen times as great as from the smaller ($4^4 = 256$; $2^4 = 16 \therefore \frac{256}{16} = 16$). The importance of this fact is well illustrated by considering the rate of flow in the capillaries. In the capillary system, the resistance from friction is greatly increased by the narrowing of the tube. Fine capillaries are about 1-11,000th of an inch in diameter. Their transverse section is, therefore, in accordance with the mathematical law that the areas of circles of different sizes are in the proportion of the squares of their diameters, 1,210,000 times smaller than that of a capillary 1-10th of an inch in diameter ($10^2 = 100$, and $11{,}000^2 = 121{,}000{,}000 \therefore \frac{121.000.000}{100} = 1.210.000$). By finding the fourth power of 11,000 ($11{,}000^4 = 14{,}641{,}000{,}000{,}000{,}000$), and dividing it by the fourth power of 10 ($10^4 = 10{,}000$) we arrive at the conclusion that, in similar circumstances, the quantity of fluid flowing out of the small capillary would be reduced to 1-1,464,100,000,000th of that passing out of the larger tube.† The rate of efflux from capillary tubes bears a relation to the density, capillarity, or fluidity of the fluid passing through them. Poiseuille shews it to be highly probable that when various salts are mingled with the serum of the blood, provided they do not coagulate it, retardation or acceleration occurs in the capillaries, according to the nature of the salt employed.

In the human body the interior of the blood-vessels is very smooth, and thus friction is reduced to a minimum. As the blood flows onwards in the arterial system, it passes from larger to smaller blood-vessels, and one might expect that consequently the velocity in the smaller vessels would be greater than in the larger. But the sum of the transverse section of a number of small branches is greater than that of the chief trunk, so that the channel widens in the same direction as that in which this subdivision occurs, and, consequently, the nearer the blood approaches the capillaries, the slower is its flow. But in the venous system, or in the passage of the lymph upwards, or in the passage of an excretion through the ramified ducts of a gland, the velocity of movement is always increasing.

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* Miller. Chemical Physics, *Op. Cit.*

† Valentin, *Op. Cit.*

5. Pneumatic Properties.—Gases are bodies, the molecules of which are in a state of constant repulsion. In a liquid, the forces of cohesion and repulsion exactly counterbalance each other ; in a gas, the repulsion predominates. In consequence of this repulsion between its molecules, a gas is highly elastic. Two physical conditions, temperature and pressure, regulate the volume of a gas. The volume of a gas is inversely as the pressure. Heat increases the repulsive force between the molecules, and, consequently, the gas expands,—the rate of expansion being 1-273 of the bulk of the gas for every centigrade degree of temperature. By the combined application of a low temperature and great pressure, many gases have been converted into liquids, and there is reason to believe that, with sufficient cold and pressure, all gases might be compelled to assume the liquid form. When a gas is confined in a limited space, it exerts a pressure equal in intensity at all points, and this pressure will be in proportion to the elastic force of the gas as controlled by temperature and pressure. This property of gases becomes of importance in cases of typhoid fever, in which there is often danger of rupture of the bowel from the accumulation of gas.

The *atmospheric air* is a mechanical mixture of nitrogen and oxygen, in the proportion of four volumes of the former to one volume of the latter. This mixture has weight or pressure, and the amount of this pressure is measured by an instrument termed the *barometer*. It consists of a glass tube A (Pl. VIII. fig. 18), perfectly emptied of air, inverted in a cistern of mercury, BC. The mercury at once rises to D—D, so that the perpendicular column of mercury is supported by the pressure of the atmosphere on the surface of the mercury in the cistern. The *mean height* of the barometric column at noon, at Greenwich, is 29.872 inches, representing a pressure of 14.617 lbs. to the square superficial inch. Thus every square inch on the surface of a man's body, is under a pressure of about 15 lbs.

According to Quetelet, the pressure on the surface of the body of an ordinarily sized man is 224 times the weight of the body. It is evident that such a pressure could not be borne, were it not the fact that this pressure is exerted on the surface of the internal cavities of the body, as well as on the external surface. There are closed cavities of the body, such as the *pleuræ*, the peritoneal cavity of the abdomen, and the synovial cavities of joints, which contain no air, and, in a healthy state, only a very small quantity of fluid, so that the atmospheric pressure maintains the walls of these cavities in close contact with each other, and favours a gliding movement of the one upon the other.

Absorption of Gases.—Solids and liquids absorb, or condense in their pores, a certain definite amount of any gas with which they are brought into contact. Solids, as a rule, absorb less gas than the same volume of liquid. When a liquid is brought into contact with a gas, the gas may either enter into a chemical combination with it, or it may not. In the former case, the amount of absorption will depend on the ordinary laws of chemical action ; in the latter, it will depend on certain conditions of temperature and pressure. Under increased pressure, the amount of gas absorbed is greater. When a mixture of two or more gases is brought into contact with a liquid, with which none of the gases enter into chemical combination, and allowed to remain for a time, a portion of each is absorbed ; but the liquid does not absorb so much of any one gas, as it would have done if that gas alone had been present, and the quantity in that case will depend upon the pressure which each gas exerts upon the liquid.*

These facts are of great importance in the consideration of the function of respiration, and the presence of gases in the blood. Recently Lothar Meyer † has found that the amounts of carbonic acid, oxygen, and nitrogen, absorbed in the blood, vary with the pressure ; but the nitrogen obeys the law of natural pressures, while only a portion of the oxygen and carbonic acid do so. That is to say, a certain amount of oxygen and carbonic acid, remains dissolved in the blood, independent of pressure ; and it is a remarkable fact, that the amount of the oxygen thus retained, is much greater than the absorbed portion. " From these facts, we may draw the interesting conclusion, that the richness or poverty of a given volume of air in oxygen can exert but a very slight influence on the total volume of oxygen contained in the blood, and therefore upon animal life." ‡

Diffusion of Gases.—All gases, even where they do not enter into chemical combination, diffuse themselves through one another, and form a uniform mixture. This phenomenon takes place even though the gases are at perfect rest, and their specific gravities different. The law which governs this diffusion, established by Graham,* is, that the relative diffusibility is inversely as the square roots of the densities. This property of gases, secures the dilution of noxious gases and vapours by pure air, and man is thus protected so far from their injurious effects. Respiration itself depends upon the process of diffusion, a fresh supply of air taking the place of that which had been rendered unfit to support life by the chemical changes which it has undergone.

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* Roscoe, Article " Gases." Watt's Dictionary of Chemistry. Vol. ii., p. 792.

† Lothar Meyer, *Phil. Mag.* (4) xiv. 263.

‡ Roscoe. *Op. Cit.* p. 804.

Transpiration of Gases.—When gases were transmitted through fine tubes by Graham,† in a series of experiments corresponding to those of Poiseuille on liquids (p. 119), he found that the rate of efflux of the gas from the tube, or rate of transpiration, as he termed it, was entirely independent of its rate of diffusion. The rate of transpiration increases directly as the pressure, with tubes of equal diameter; the volume transpired in equal times, is inversely as the length of the tube; and as the temperature rises, the transpiration of equal volumes becomes slower. Of all the gases tried, oxygen has the slowest rate of transpiration. The bearing of these facts on the function of respiration, is not yet evident, but they no doubt affect it more or less.

6. Properties relating to Heat.—The term heat is used to express a peculiar sensation, but it also describes the condition of matter which produces that sensation. Our sensations, however, do not inform us of the actual amount of the heat of any object, but they bear testimony to the fact, that it imparts that sensation to our bodies, or removes it. A body having a certain fixed temperature, may appear to our sense of touch to be hot at one time and cold at another.

What is heat? Two theories have been advanced to answer this question: 1st. The *emission* theory, which states that the molecules of all bodies are surrounded by a subtle fluid, which has the power of passing from one body to another. When this fluid enters our body, we feel warm; when it leaves it, we feel cold. 2d. The *undulatory* theory, which asserts that heat is not a fluid, but a *condition of matter* easily transferable from one portion of a substance to another. This condition of matter is believed to be an oscillation of its particles, and the more rapid and extensive these oscillations, the higher is the temperature. This latter view is also termed the *dynamical theory of heat.* According to it, heat is a *mode of motion*, not a material substance. Count Rumford was the first, in 1798, to advance this theory. In the following year, 1799, Sir Humphrey Davy shewed experimentally that heat could not possibly be matter, as it could be actually created by friction. For many years, this explanation of heat was not generally accepted; but the investigations of several philosophers, of whom we may mention Carnot, John Thomson, Seguin, and Colding, tended to support it. It was, however, reserved for Mayer of Heilbronn, by theory and calculation, in 1842, and Joule, of Manchester, by direct experiments made in the years 1843, 1844, 1847, and 1849, to settle the question, by determining the *mechanical equivalent of heat.* They shewed that heat could be measured accurately, and that it always represented, and was the result of, a certain amount of work; and they established the great fact, that heat is simply another form of possible force or *energy.* It is never lost or destroyed; but it may be resolved into other forms of energy. By the term, mechanical equivalent of heat, is meant that the mechanical force represented by a fall of 772 lbs., through the space of one foot, will produce the quantity of heat capable of increasing the temperature of a pound of water by 1° Fahr.* The dynamical theory is the one generally adopted. For the application of this theory to vital phenomena, see Correlation and Conservation of Force under Vital Properties of the Tissues.

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* Graham, *Phil. Mag.* 1833, vol. ii.

† Graham, *Phil. Trans.* 1846, p. 591; and 1849, p. 349.

Sources of heat.—1. The sun. The amount of heat received by the earth from this source in one year would be sufficient to melt a layer of ice one hundred and five feet thick, spread over the surface of the earth.† 2. The internal heat of the earth, which shews itself in hot springs, volcanoes, &c. 3. Friction of one body upon another. The amount of heat derived from this source alone is immense. 4. Chemical action. More or less heat is always developed during chemical action. Under this head may be classed heat developed by living beings, which is the result, as will be explained more fully hereafter, of chemical changes taking place in the tissues. (See Animal Heat.)

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* For further information on this subject, reference is made to Rumford, *Philosophical Transactions*, 1798; Davy, Chemical Philosophy, 1812; Mayer, Die Mechanik der Wärme, 1867; Tyndall on Heat, 3d ed.; Bence Jones, Croonian Lectures on Matter and Force; Helmholtz Lectures, *Med. Times*, 1864; Professor Tait, Sketch of Thermo-dynamics, 1868.

† Tyndall, Heat as a Mode of Motion, 3d ed.

Effects of heat.—1. Heat elevates temperature, that is, it not only causes a body to produce the sensation of heat, but it increases its tendency to impart heat to other bodies. 2. Heat causes bodies to expand, and converts solid bodies into liquids, and liquids into gases. 3. Heat produces chemical changes, and it also modifies the magnetic, electrical, and optical properties of bodies.*

Specific heat.—It has been found by numerous experiments that the quantity of heat needed to effect a given change of temperature is different for almost every substance; and these quantities of heat are termed the *specific heats* of the substances. The standard of comparison is the amount of heat required to raise the temperature of an equal amount of water from 0 to 1°C. For instance, the statement that the specific heat of alcohol is .615, implies that the quantity of heat that would suffice to raise the temperature of any given quantity of alcohol from 0° to 1°C, would raise the temperature of an equal quantity of water only from 0° to 0.615. Bright arterial blood has a specific heat of 1.03, and dark venous blood of .89. Muscle shews a specific heat of .74, and fatty bodies .40 to .45. The gases concerned in respiration have small specific heats. Thus, the specific heat of air is .2374; of oxygen, .2175; of nitrogen, .2438; and of carbonic acid, .2163. The specific heat of the same body is commonly greater in the liquid than in the solid state, and always less in the gaseous than in the liquid state.

Changes produced by heat upon gases, liquids, and solids.—As a general rule, all bodies expand on the application of heat. This is due to molecular repulsion. Gases expand at the rate of 1.273d of their volume for every degree centigrade. Liquids also expand, but there is no general law regulating their expansion, as in gases; for it is found that not only has almost every liquid a co-efficient of expansion different from that of any other, but the co-efficient of the same substance varies much with changes of temperature. Solids also expand, but they vary much in the rate of expansion.

Fusion.—When a body is heated to a certain point it melts, or assumes the liquid form; when it cools, it resumes the solid form, or solidifies. The temperature at which these phenomena take place varies much. Sulphurous anhydride (SO_2) melts at 80°, tin at 235°, silver at 1000°, and platinum at 2000°. A liquid cooled slowly, and protected from all mechanical disturbance, will not solidify till it has been cooled 10° or 12° below its ordinary point of solidification. In this way, water may be made to freeze at 15° instead of at 0°.

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* Foster, Article "Heat," in Watt's Dictionary of Chemistry, vol. iii. p. 17.

Vapours.—When a little water is exposed to the air, part of it disappears into the atmosphere in the form of vapour. In the case of water, evaporation takes place at all temperatures. When a liquid evaporates in an enclosed space, the amount of evaporation depends on the nature of the liquid, on the temperature, and on the extent of the space. After the space is filled or saturated with vapour, the vapour, in virtue of its elasticity as a gas, exerts a certain amount of tension upon the surface of the liquid, and prevents further evaporation. But if the vapour itself is now submitted, either to pressure or cold, part of it passes again into the liquid state. If, on the other hand, the pressure on the vapour be diminished, or its temperature raised, more vapour is formed in the same space till saturation is again produced, and the tension of the vapour is greater. Evaporation is more rapid in a dry than in a moist atmosphere. The larger the amount of vapour present in the atmosphere, the smaller will be the quantity of aqueous vapour which rises from an exposed surface, and *vice versa.* Evaporation also goes on more rapidly in a strong breeze or current of air than when the air is still. Hence the frequency of catarrh or "cold," and of pulmonary disorders in those who reside in a climate where cold dry east winds prevail.

Boiling or ebullition.—This phenomenon takes place when heat is applied to the lower part of a mass of liquid, and the tension of the vapour produced at the point where the heat is applied, is greater than the pressure of the atmosphere on the surface of the liquid. Bubbles of gas then escape through the superincumbent liquid.

Latent heat.—This term was first used by those philosophers who held that heat was a material substance. When a liquid is changed by heat into a vapour, a certain amount of heat is absorbed, chained up, or made latent, and conversely, when a vapour returns to the liquid state, the same amount of heat is set free. According to the dynamical theory of heat, when heat disappears, or is made latent, it is not lost, but its equivalent is found in the work done in altering the molecular constitution of the substance. Thus the formation of vapour cools bodies, and the condensation of vapours to liquids causes warmth. The temperature of the body is lowered by evaporation from the skin. The amount of evaporation being in proportion to the external temperature, its effect is to keep the blood at or near a uniform temperature. (See Animal Heat.)

Relation of chemical affinity to heat.—Chemical action being the result of molecular forces, is always accompanied by the appearance or disappearance of heat. A given amount of chemical action produces a given amount of heat, and conversely, the same amount of heat is required to undo the chemical action that has produced it. Numerous experiments have been made to estimate the amount of heat produced by a definite amount of chemical action, and the amount is always expressed as so many *units of heat*, a unit of heat being the amount of heat required to raise 1 gramme of water from 0° to 1°C.

The following table gives the quantities of heat, expressed in *heat units*, evolved in the combustion of various substances in oxygen* :—

Substance.	Product and Formula.	Units of Heat.
Hydrogen, . . .	H_2O	33881
Carbon, . . .	CO_2	7900
Sulphur, . . .	SO_2	2220
Carbonic acid, . . .	CO_2	2403
Ether, ...	$C_4H_{10}O$	9028
Stearic acid, . . .	$C_{18}H_{36}O_2$	9716

From this table it is apparent, that when substances rich in carbon and hydrogen (especially the latter) unite with oxygen, a large amount of heat is evolved, a fact which will be seen to be of great importance when we treat of respiration and animal heat.

Conductivity.—Some bodies conduct heat better than others. Surround a body by a badly conducting substance and it may be kept warm for a long time. If we heat the end of a wire in the flame of a spirit lamp, the other end of the wire speedily becomes so hot that we cannot hold it, because the wire is a good conductor of heat. Platinum is a better conductor than iron, iron than lead, lead than marble, and marble than brick. Gold is the best conductor. All organic substances, such as hair, wool, cotton, straw, are bad conductors. Our clothes themselves are not warm, but they prevent our bodies from losing heat because they are bad conductors.

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* Foster, *Op. Cit.*

Radiant Heat.—Radiant heat is heat transmitted from one body to another, without altering the temperature of the intervening medium. All bodies at all temperatures radiate heat. Radiation takes place in all directions, and if through a homogeneous medium, the rays pass in straight lines. If the rays pass from one medium to another differing in density, they are refracted just as rays of light are. Rays of radiant heat may pass through a vacuum. The chief law governing the intensity of radiant heat is that the intensity is inversely as the square of the distance.

Tyndall's researches upon Radiant Heat.—It is well known that from a luminous object, such as a gas flame, two sets of rays pass out, rays of light and rays of heat. The heat rays are far more numerous than the light rays, and their presence may be shewn by directing them to the blackened surface of a thermo-electric pile. Tyndall found that certain substances allow the heat rays to pass through them while they absorb the light rays. Iodine is opaque to light, but it permits heat to pass through it. Bodies capable of transmitting heat are said to have the property of *diathermancy*, bodies which have the power of stopping radiant heat have that of *athermancy*. There is no connection between diathermancy and transparency. Smoky quartz, for instance, which is nearly opaque, transmits heat well, while a clear crystal of alum absorbs much of it. Tyndall has also found that many gases and vapours absorb heat. Dry air absorbs very little heat, but air containing aqueous vapour absorbs a considerable quantity. Consequently, whenever the air is dry, terrestrial radiation goes on rapidly and produces great cold. Tyndall thus describes the great function of aqueous vapour in the atmosphere * :—" Aqueous vapour is a blanket more necessary to the vegetable life of England than clothing to man. Remove, for a single summer night, the aqueous vapour from the air which overspreads this country, and every plant capable of being destroyed by a freezing temperature would perish. The warmth of our fields and gardens would pour itself unrequitted into space, and the sun would rise upon an island held fast in the iron grip of frost."

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* Tyndall, *Op. Cit.*

7. PROPERTIES RELATING TO ACOUSTICS.—Acoustics is the study of sounds, and, under the same term, is sometimes included the study of the vibrations of elastic bodies. Sound is the result of the rapid oscillations of the particles of the air communicated to the organ of hearing. Each particle moves only a slight distance to and fro, and this motion of a number of contiguous particles produce what is termed a *sonorous wave*, which impinges on the *membrana tympani* and causes it to vibrate. This vibration is transmitted to the expansion of the auditory nerve in the inner chambers of the ear; an impression travels along the nerve to the brain, and *we hear*. No sound can pass through a vacuum. A bell rung by clockwork or electricity beneath the receiver of an air-pump, gives forth no sound. The *intensity* of sound is governed by certain laws. It is always inversely as the square of the distance of the body from the ear. The greater the extent of the vibrations of the sonorous bodies, the more intense is the sound. If a long vibrating cord be made to oscillate, the oscillations are perceptible to the eye, and it will be observed that as the oscillations diminish in extent, the sound becomes less intense. The density of the medium in which a sound is produced also affects its intensity. A bell rung in a heavy gas like carbonic acid is much more intense than when it is rung in a light gas like hydrogen. A sound is more intense in a medium at rest than in a medium in motion, and thus sounds are heard better in a calm than in a windy day. The proximity of a sonorous body intensifies sound. The violin is a sounding box, above which vibrating strings produce sounds much more intense than if caused to vibrate in free air. The reason of this is, that the air in the box and the box itself vibrate in unison with the air.

If a wave of sound be confined in a tube having a smooth internal surface, it may be conveyed to great distances without losing its intensity to any sensible degree. The speaking tube extensively used in places of business, and the *stethoscope*, an important instrument in the hands of the physician, are illustrations of the application of this fact in acoustics.

Velocity of sound.—A wave of sound takes a sensible amount of time to travel from one place to another. In ordinary air, at a temperature of 0°C, the velocity of sound is 1090 feet a second, and it augments about 2 feet for every degree centigrate added to its temperature. Sound travels much more slowly than light; hence we see the lightning flash some time before we hear the thunder. If a discharge of thunder takes place from an elongated cloud, a prolonged thunder roll is heard, which is intensified by the echoes of the clouds. Sound travels in water, as determined experimentally by Collodon and Sturm in 1827, at a velocity of about 4708 feet in a second, or more than four times as rapid as it travels in air. The velocity of sound in wood is about sixteen times as great as in air.

Echoes.—An echo is a repetition of a sound in the air, caused by its reflection from a solid body. The laws regulating the reflection of sound are exactly the same as those of light, and will be referred to when we discuss optical phenomena (p. 135). Sound is reflected by solid surfaces, such as rocks, and walls, and also by clouds. The vibrations of the air are reflected by the ridges and depressions of the external ear, so as to be directed as much as possible into the *meatus.* When sound travels from one medium of a certain density into one of another density, it is partially reflected, and in this way is weakened.

Musical sounds.—Sound may be either *musical* or it may constitute what is termed a *noise.* When a number of sonorous waves impinge upon the *membrana tympani* at regular intervals and sufficiently rapid, a pleasurable sound is experienced, which we call a *musical note.* If the waves come in a series of irregular shocks, a noise is produced. A series of taps produced in any way and with great rapidity, gives rise to a musical note. The taps of a card against the cogs of a rotating wheel, as first shewn by Savart, illustrates this point.* A series of puffs at equal intervals, and rapidly following each other, results in a musical note. This phenomenon is illustrated by an instrument called the syren, first made by Cagniard de la Tour, in which a series of puffs is produced through perforations in a rapidly rotating disk. When the taps or puffs follow each other slowly, a series of shocks on the *membrana tympani* is experienced, and as they increase in rapidity the pitch of the sound rises, and a musical sound is produced. The human ear is so constituted that if the vibrations number less than sixteen a second, we are conscious only of shocks; and if they exceed 38,000 a second, the pitch becomes so high that the note cannot be heard. The range of the best ear covers about eleven octaves, and the sounds available in music are comprised between the limits of seven octaves. The muscular sound, or *susurrus*, first observed by Wollaston in 1809, which may be heard easily by applying a stethoscope over a vigorously contracting muscle, is produced, according to Collongues and Haughton, by thirty-four vibrations per second. *Tinnitus aurium*, or singing in the ears, resembles a sound produced by 2048 vibrations.

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* Tyndall on Sound. 1867.

A musical tone has three qualities, *pitch*, *intensity*, and *timbre*. Pitch depends on the number of vibrations per second yielded by the body producing the note. Intensity, as has been already explained, depends on the *extent* of the vibrations of the sonorous body. Timbre is that peculiar quality of a note which distinguishes it when sounded on one instrument than when sounded on another. Thus, if the note C on the treble stave be sounded on a pianoforte and a violin, it will have 512 double vibrations a second in both, but the quality of the two will be so obvious that they cannot be confounded.

Physical theory of music.—Musical notes are separated from each other by intervals, and they bear a certain relation to each other. Suppose a note produced by a certain number of vibrations, it will be found that a note which is produced by double that number of vibrations will closely resemble the first one. The higher note will differ from the lower only in pitch, and is said to be the *octave* of it. The series of sounds which connect a given note with its octave is called a *scale*, and the notes are denoted by the letters C, D, E, F, G, A, B. The scale is repeated by taking the octaves of these notes *c*, *d*, *e*, *f*, *g*, *a*, *b*, and again repeated by another octave *c′*, *d′*, *e′*, *f′*, *g′*, *a′*, *b′*, and so on. It has been found by experiment that if *m* represent the number of vibrations corresponding to C, the fundamental note of any octave, the other notes will be indicated by the following number of vibrations,—

Names, . .	C,	D,	E,	F,	G,	A,	B,	C,
Intervals, . .	1st	2d	3d	4th	5th	6th	7th	8th
Rates of vibrations,		$\frac{9}{8}m$	$\frac{5}{4}m$	$\frac{4}{3}m$	$\frac{3}{2}m$	$\frac{5}{3}m$	$\frac{15}{8}m$	$2m$.

These eight notes constitute the *natural* or *diatonic* scale. If we multiply these ratios by 24, so as to avoid fractions, we obtain the following whole numbers, which express the relative ratios of the vibrations of the notes of the scale,—

27, 27, 30, 32, 36, 40, 45, 48.

The intervals, or ratios of the times of vibration of each note to the note next below it, are represented as follows,—

C to D,	D to E,	E to F,	F to G,	G to A,	A to B,	B to C.
$\frac{8}{9}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

The intervals $\frac{8}{9}$, $\frac{9}{8}$, and $\frac{10}{9}$ are called *tones*, and exist between C and D, D and E, F and G, G and A, and A and B; the interval $\frac{16}{15}$ is what is termed a *semitone*, and is found between E and F, and B and C. There are thus in the natural scale five tones and two semitones. If C, E, G, are sounded together on the keys of a piano, we have what is termed a *major triad.* This is the *tonic* or first major triad. When G, B, D^2 are sounded, we have the *dominant* or second major triad; and when F, A, C^2 are sounded, we have the *sub-dominant* or third major triad. The number of vibrations of the three notes C E G, G B D^2, and F A C^2 are all in the proportion of 4, 5, 6; and a scale formed in this way of major triads is a *major* scale. In it, the semitones fall between the third and fourth, and seventh and eighth notes. In what is called a *minor scale*, the semitones are between the second and third, and seventh and eighth notes, the sixth and seventh being raised a semitone; but in the descending minor scale the semitones are between the sixth and fifth, and third and second. When a series of notes are separated only by semitones, produced by interpolating other notes, we obtain a *chromatic scale.* The notes so interpolated in the five intervals called tones do not receive special names, but are called the *sharps* and *flats* of the natural notes above or below which they occur. A chromatic scale is seen in Plate VIII. fig. 19*a*.

Harmonics.—When one of the keys of a musical instrument, such as a piano, is touched, the note corresponding to that key is not the only note sounded, but a series of other notes, each of less intensity than the one preceding it, are also produced, which blend with the primary note so as to give the mind the sensation of one sound. Helmholtz calls the first note the *primary tone*, and the other notes the *harmonics of the primary tone;* and he has shewn that the timbre of a note produced on different instruments depends on the different intensities of the harmonics which accompany the primary tone of the sound. The pleasure experienced on sounding two notes, such as C and its octave, depends on the harmonic notes that accompany the primary note. These sounds which please the sense of hearing when played together are called *concords*, and those which do not, are called *discords.* Two notes, differing from each other by an octave, played together, produce a more agreeable sound than any other two notes. The first and fifth notes also produce an agreeable sound.

Compass of the Human Voice.—The compass of the voice varies in individuals. In Plate VIII. fig. 19. is a scale of the human voice, shewing the mean compass of its different varieties of *bass*, *tenor*, *alto*, and *soprano.* The male bass voice begins at the first F and extends to F3. The tenor begins at C1 and extends to C3. The voices of women, boys, and eunuchs begin at F2 for alto, and usually reach as high as F4. The soprano, usually sung by women, begins at C2 and extends as high as C4. What are termed *barytone* voices are intermediate between bass and tenor, begin at A and extend to F2. The *mezzo-soprano* is intermediate between alto and soprano. The lowest note of the female voice is, therefore, an octave higher than the lowest of the male voice ; and the highest note of the female voice about an octave higher than the highest of the male. The compass of the male and female voices together include four octaves.

Vibrations of Strings.—When a string is stretched from one point to another and caused to vibrate, the number of vibrations is always inversely as the length of the string ; and the musical note produced varies according to the number of vibrations. But the note is not a simple one, for it is made up of the primary note of the string produced by the primary vibrations, and of a series of partial secondary vibrations which produce the harmonics of the primary note.

Vibrations of Rods.—Rods of wood, of glass, and of steel, being very elastic, readily vibrate ; and the law regulating these vibrations is that the number of vibrations made in a given time by the rods is directly as their thickness, and inversely as the square of their length. The common tuning fork is an example of vibrations of this kind. It is chiefly by the vibrations produced in the *malleus*, *incus*, and *stapes*, the small bones of the *tympanum*, that sound is conveyed to the inner ear.

Vibrations of Membranes.—Membranes vibrate if they are stretched, like the skin of a drum. They vibrate either by direct percussion, as in the drum, or they may be set in vibration by the vibrations of the air, as is the case in the vibrations of the *membrana tympani.* The sound of vibrating membranes is acute in proportion as they are smaller, thinner, and more tightly stretched, circumstances which alter the tone of the cardiac sounds.

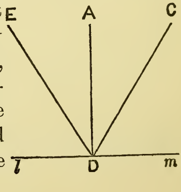
8. Properties relating to Optics.—Light, by its action on the retina, makes us acquainted with the existence of bodies. It is also a most important agent in working chemical changes.

Theories of Light. — Two theories have been entertained : 1. The *emission theory*, which supposes light to consist of minute particles emitted from luminous bodies. The greatest exponent of this theory was Newton. But as the knowledge of optical phenomena advanced, many facts were discovered which could not be accounted for by the emission theory, and it has accordingly given place to—2. *The undulatory theory*, which supposes that objects are made visible by the vibrations of luminous bodies in an elastic medium, termed *the ether*, which pervades all space. This theory is the one now generally held by natural philosophers. The velocity of light is about 196,000 miles per second.

When a body emits light, such as a gas flame, it is said to be *luminous.* When a body transmits light so that objects can be seen through it, like glass, or water, or the cornea, it is *transparent* or *diaphanous.* What is termed a *translucent* body, transmits light, but objects cannot be seen through it. Ground glass or a cornea, rendered hazy by inflammation, are examples of *translucency.* A body is *opaque* when it does not transmit light.

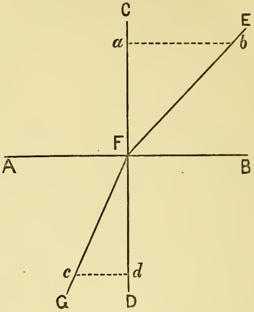
Propagation of Light.—In a homogenous medium, light passes on in a perfectly straight line. If, in its course, it meets with a different medium, it is bent or *refracted;* if it impinges on a body it cannot penetrate, it glances off it, or is *reflected.* Rays of light may either run parallel to each other, or they may separate or diverge from each other, or they may converge so as to meet at one point, termed the *focus.*

Reflection of Light.—When a luminous ray impinges upon a polished surface, it is reflected from it. Let *l m* be a plane reflecting surface, C D, the ray of light falling on it, termed the *incident ray*, A D, a line drawn perpendicular to the surface, and D E the reflected ray. The angle C D A, is called the angle of incidence, and the angle A D E, the angle of reflection. The



angle of reflection is always equal to the angle of incidence, and the incident and reflected rays are both in the same plane, which is perpendicular to the reflecting surface. A certain amount of light is, however, lost, as the quantity in the reflected ray is less than in the incident ray. The phenomena of reflection are seen in mirrors. Mirrors may be either plane, convex, concave, spherical, &c. In a *plane* mirror, like what is in ordinary use, the image is formed behind the mirror at a distance equal to that of the reflected body from the mirror ; and in such a mirror the image is of the same size as the object (Plate VIII. fig. 20), When an object is placed before a *concave* mirror, the image is inverted, and is formed in front of the mirror, in its focus, or point to which the reflected rays converge ; and the image is much smaller than the object, the size being inversely in proportion to the concavity of the mirror (Pl. VIII. fig. 22). The image produced by a *convex* mirror is behind the mirror, and is always erect (Plate VIII. fig. 21). The size of the image is to the size of the object, as the distance of the image from the centre of the mirror is to the distance of the object. In approaching the mirror, the image and object approach to equality in size. These various phenomena may be readily seen in the human eye. The anterior surface of the cornea, and the anterior surface of the crystalline lens, are both convex mirrors, and the concavity in the vitreous humour, corresponding to the posterior surface of the lens, or the posterior surface of the lens itself, acts as a concave mirror. Consequently, on holding a candle before the eye, we see three reflections : 1st, an erect image, produced by the anterior surface of the cornea, that moves upward when the candle is moved upwards ; 2d, an erect and smaller image, produced by the anterior surface of the crystalline lens, which also moves upwards when the candle is moved upwards ; and 3d, a small and inverted image, produced by the posterior surface of the lens, or the anterior surface of the vitreous humour, that moves downwards when the candle is moved upwards. A knowledge of these facts, first described by Cramer, enabled Helmholtz, by means of the *ophthalmometer*, to settle the question of the accommodation of the eye to distance. (See Sight.)

Refraction of Light.—When one half of a straight stick is immersed in water, it will appear crooked or bent into an angle at the point where it enters the water. If it were immersed in alcohol, the bend would be greater than in the case of the water. Let A B represent the surface of the refracting medium, such as water, and E G a ray of light passing from a rarer medium, such as the air, through it; E G will be bent at F towards the line C D, perpendicular to the surface of the liquid. The angle E F C is termed the *angle of incidence*, the angle D F G, the *angle of refraction.* If C D had represented a ray of light, it would have passed straight on without refraction, because it is perpendicular to the surface, but when a ray passes into the fluid at an angle, it will always be refracted or bent towards C D. When the ray passes out of a rare into a dense medium, as from air to water, the angle of incidence is greater than the angle of refraction; and when the ray passes out of a dense into a rare medium, as out of water into air, the angle of incidence is less than the angle of refraction. Now draw the lines, *a b* and *c d*. The first, *a b*, is the *sine* of the angle of incidence, the other, *c d*, the *sine* of the angle of refraction; and the refracting power of different bodies is indicated by the ratio these two sines bear to each other, this ratio being termed the *index of refraction.*



The following table shews that bodies vary in their power of refracting light, when it passes from one medium to the other:—

Name.	Sine of the Angle of Incidence is to the sine of Angle of Refraction as,
Water, . . .	1.336 is to 1
Ether, . . .	1.057 is to 1
Alum, . . .	1.457 is to 1
Crown glass, . .	1.534 is to 1
Plate glass, . . .	1.542 is to 1
Canada balsam, . .	1.549 is to 1
Ruby, . . .	1.779 is to 1
Diamond, . . .	2.439 is to 1
Cornea, . . .	1.330 is to 1

Lenses.—A lens is a transparent medium which, from the degree and kind of curvature of its surfaces, has the property of causing luminous rays to converge or to diverge. They may be of six kinds: 1. double convex (Pl. VIII. fig. 23, 1); 2. plano-convex (Fig. 23, 2); 3. converging concavo-convex (Fig. 23, 3); 4. double concave (Fig. 23, 1^1); 5. plano-concave (Fig. 23, 2^1); and 6. diverging concavo-convex (Fig. 23, 3^1).

Spherical aberration.—The rays refracted by the margins of the lens are more refracted than those nearer the centre, and consequently the former come to a focus at a point nearer the lens than the latter. This phenomenon is termed the *spherical aberration* of the lens, and as it produces an indistinct image, it is always corrected in perfect optical instruments. How this is done in the case of the compound microscope will be explained in the third part of this work. (See Practical Histology.)

The *focus* of a lens is the point where the refracted rays or their prolongations meet.

Images are formed by lenses in the same manner as they are formed by mirrors. When an image is formed by a convex lens, it is inverted in position relatively to the position of the object, and the size of the image is to that of the size of the object as its distance from the lens is to the distance of the object from the lens. The crystalline lens is a lens of this kind, and the radii of its curvatures are such that it brings the rays of light emitted from a luminous body placed before the eye to a focus upon the retina.

Interference of rays of light.—When two rays of light, proceeding from two radiant points placed very close together, meet one another in such a manner as to counteract or modify each other's action, *interference* is produced. Light, according to the hypothesis generally accepted, consists of undulations or waves in the luminiferous ether. It is quite evident that two waves may meet in such a way as the one will entirely destroy the action of the other. When this is the case, there is darkness by *complete interference.*

Diffraction.—When light passes by the edge of an opaque body, or through a small opening, a number of alternate bright and dark bands or coloured fringes is seen around it. This is the result of diffraction, a modification of the luminous rays in virtue of which they become bent or inflected round the edge of the opaque body, just as a wave of water will turn the angle of a wall or spread itself through a narrow opening.* Diffraction may be seen in the fringes produced by rays passing along the edge of a screen, or the edge of a mirror, or at the side of narrow rectangular openings.

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* Roscoe, Article "Light," Watt's Dict. of Chem., vol iii. p. 601.

Dispersion of light—When a narrow beam of sunlight is passed through a glass prism and received upon a screen, an image called a *spectrum* is produced, shewing a series of colours in the following order: red, orange, yellow, green, blue, indigo, violet. The arrangement is seen in Pl. VIII. fig. 26. Let a pencil of rays, S, be admitted into a dark room through the hole H in the shutter E F, it would be carried in the direction of the dotted lines, and appear as a white spot of light on the wall. But if the prism A B C be placed before the hole, the rays of light will be refracted so as to produce the prismatic spectrum M N. The red rays are less refracted than the orange, the orange than the yellow, the yellow than the green, the green than the blue, the blue than the indigo, and the indigo than the violet. This grand discovery was made by Sir Isaac Newton, and was stated by him as follows:—Solar light may be separated into a number of rays of different colours. To each colour there corresponds a definite degree of *refrangibility*, or degree of refraction; the red rays being the least, the violet rays the most refrangible, and the intermediate colours increasing regularly in refrangibility from the red to the violet. When these colours are reunited, a beam of white light is produced.

Fraunhofer's lines.—In 1802, Wollaston, by viewing through a prism a ray of light admitted through a narrow opening in a shutter, discovered a number of fine dark lines parallel to the edge of the prism, or to the boundary lines of the several colours; and in 1807, Fraunhofer of Munich, without being acquainted with Wollaston's observations, made the same discovery in a spectrum formed by a telescope. These lines, usually called *Fraunhofer's lines*, are mostly perfectly black. They are irregularly distributed through the spectrum. Eight of the most distinct of them are denoted by the first eight letters of the alphabet, beginning from the red of the spectrum. Kirchoff has observed 2000 lines, and has laid down a very elaborate map of the solar spectrum.

Kirchoff* has advanced an ingenious theory to account for these lines. When sodium is ignited, a spectrum is produced in which two bright bands correspond with the double line D of the solar spectrum; and if through a flame, coloured by sodium, rays from an oxyhydrogen lime light, or from an electric light, be projected, the continuous spectrum produced by either of these sources of light is interrupted by a black line coinciding with the solar line D. In like manner, the spectra of potassium, copper, &c., may be represented by dark lines, or be, to use the phraseology of Kirchoff, *reversed.* On these facts Kirchoff founds an explanation of the lines. He supposes the luminous atmosphere of the sun contains the vapours of various metals, which vapours absorb some of the rays of light proceeding from the intensely heated liquid nucleus of the sun, so that the lines are only the reversed bright lines which would be visible if the nucleus did not emit rays of light. Practically, these facts have introduced a new era into chemical investigation. By means of what is termed *spectrum analysis*, even new elements have been discovered, and the extensive distribution of many elements has been recognised. It has also been applied to physiological research. The hydrochloric acid solution of the ash of human tissue gives a spectrum, shewing the presence of potassium, sodium, lithium, rubidium, cæsium, and calcium. The spectral phenomena of the blood have already been described (p. 32). Bile and urine also give *spectra*, but not very characteristic.

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* Kirchoff. Researches on the Solar Spectrum, and on the Spectra of the Chemical Elements, translated by Roscoe. 1868.

Fluorescence.—If we fill a clear glass bottle with a solution of sulphate of quinine, and carefully examine it, we shall find that when looked at by transmitted light, it is colourless, but when viewed in reflected light it presents a bluish colour. This is due to fluorescence, a phenomenon first explained by Professor Stokes.* He found that light separates itself into three sets of rays: heat rays, colour rays, and a third set of rays which were usually invisible to the human eye. These rays are of a peculiar bluish colour, and come from the part of the spectrum a little beyond the extreme violet (Plate VIII. fig. 26). These blue rays are remarkable for their very powerful chemical action, and immediately affect chloride of silver and other photographic preparations, and they are rendered visible by a solution of sulphate of quinine, because the atoms of this fluid are transformed by them into self-lighting bodies, so that when placed in these rays they emit a peculiar bluish light. An alcoholic solution of chlorophyll, in this way, produces a red light, tincture of turmeric a greenish, a decoction of madder mixed with alum a yellow, and so on. Dr Thudicum has applied to physiological chemistry the method of obtaining fluorescence recommended by Professor Stokes, and by its aid has been able "to identify many substances, and to discover at least five new bodies."*

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* Stokes, *Phil. Trans.* 1852. *Journal Chem. Soc.* 1864.

Chromatic aberration.—A lens may be supposed to be a combination of two prisms. Consequently, light passing through it is decomposed, and as the red rays are less refrangible than the violet, they are brought to a focus farther from the lens than the violet rays. In like manner, each colour of the spectrum has its own focus, and thus, when an object is examined by such a lens, a fringe of colour is seen around it. By combining lenses of substances having different dispersive powers, and so arranged that the dispersive power of the one substance is counteracted by that of the other, the images of objects viewed through such lenses do not appear coloured. When light is thus refracted without decomposition, what is termed *achromatism* is produced, and the lens is an *achromatic lens.* The lenses of the human eye produce an achromatic combination.

Colours of thin plates.—Thin films, or laminæ of all transparent substances, appear coloured with very bright tints, especially by reflection. A drop of oil spread over the surface of water shews all the colours of the spectrum. The thin film of a soap bubble exhibits brilliant irridescent colours, especially at its thinnest part. When a thin layer of air is pressed between two parallel surfaces of glass in strong daylight, there is seen at the point of contact a black spot surrounded by six or seven coloured rings. These are known as *Newton's rings.* All these phenomena are produced by the interference of light, which has been already described.

Colour of fibres and grooved surfaces.—It has been long known that mother of pearl, the scales of many butterflies, the wing-cases of beetles, the feathers of birds, the scales of fishes, and some hairs, such as those of the annelid called the *Aphrodite* or sea mouse, shew beautiful irridescent colours when viewed by reflected light. This appearance is due to the existence of minute grooves upon the surface of these bodies. Sir David

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* Thudicum, Appendix to Tenth Report of Med.-officer of Privy Council. 1867. P. 200.

Brewster,* who investigated this subject in 1833, allowed melted wax, gum arabic, or isinglass, to indurate upon a surface of mother of pearl, and found that the surface of the mould or cast shewed the irridescent colours of the mother of pearl. These were produced by an exact impression having been made on the wax, or other substance, of the grooves on the mother of pearl, the number of which is so great as 3000 in an inch. When plates of steel, gold, silver, lead, tin are covered with fine grooves, they shew the same phenomena. The presence of oil upon the grooved surface increases the number and distinctness of the colours. The same phenomenon is also seen on fragments of glass which have been long exposed to the corroding action of the air or earth. These colours are due to reflection. Experimenting with plates of steel artificially grooved, Sir David Brewster found the following results :—

No. of grooves in square inch.	Tint produced.
312	White.
1000	Yellowish green.
2500	Blue.
3333	Gamboge yellow.
10000	Fine blue.

Colours.—Colours are *simple* or *compound.* Simple colours are those of a pure spectrum ; compound colours are produced by the mixture of two or more of the simple or primary colours. It was once held that there were three primary colours, red, blue, and yellow ; and that all the other colours of the spectrum could be produced by combinations of these. Helmholtz † has, however, shewn that at least five are necessary, red, yellow, green, blue, and violet. Every colour has a *complementary colour*, or rather a number of complementary colours, by uniting with which it produces *white* light.

Polarisation of Light.—When a ray of light falls upon the surface of most transparent bodies, such as water, glass, and certain crystals, it is refracted according to the law of sines (see p. 136) already explained. But many bodies, such as hair, horn, shells, resins, gums, jellies, &c., refract the ray of light, so as to divide it into two different rays, more or less inclined to one another. The separation of the two rays is sometimes very great. This phenomenon is termed *double refraction*, and the body producing it is a *doubly refracting* body. A rhomb of transparent, colourless, Iceland spar, is admirably fitted for shewing double refraction. This will be readily understood by studying Fig. 24 in Plate VIII. Let A X be a prism of Iceland spar, resting on a sheet of white paper, having a black line M N drawn upon it. If we now look in the direction of R *r*, we see that the line M N is double, two lines, M N, *m n*, being distinctly visible. On turning the crystal round, still maintaining the same face on the paper, we see that in one position only, the two lines coincide with each other. This one direction, in which the division of the ray does not take place, a direction parallel to the line which connects the two obtuse angles of the crystal A X, is called the *optic axis*. These phenomena are accounted for by the fact, that the ray of light R *r*, is refracted by the action of the surface into two pencils, *r* O, *r* E, each of which being again refracted by the under surface of the rhomb, at the points E O, will move in the direction E *e*, O *o*. The line *r* O, is called the *ordinary* ray, the index of the refraction being 1.654; the line *r* E, the *extraordinary* ray, the index of refraction 1.483, being less than that of the ordinary ray. These rays are not only equal in intensity, but they possess other properties, which are expressed by saying, they are *polarised*. They are called *rays* of *polarised light*, because they have sides or poles of different properties, and planes passing through them, are called *planes* of *polarisation*. The properties of a polarised ray all relate to changes of intensity or modifications of colour. Light may be polarised in the following ways :—1. By reflection from the surface of a transparent medium, such as a plate of glass. 2. By ordinary refraction. 3. By double refraction. When light is polarised by this latter method, both the ordinary and extraordinary rays are polarised ; and it is often convenient to throw one or other of these rays completely out of view. This may be done either by *reflection* or by *absorption*. The apparatus used for throwing out the ray by reflection, is called a *Nichol's prism* (Pl. VIII. fig. 25), which consists of two similar prisms of Iceland spar, cut in a particular manner, and cemented together with Canada balsam. A ray of polarised light may also be absorbed by means of a plate of tourmaline, cut so as to allow the extraordinary ray to pass through polarised, while the ordinary ray is completely absorbed.

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* Sir David Brewster, Optics. *Op. Cit.*

† Helmholtz, *Ann. Chim. Phys.* (3) xxxvi.

When a ray of polarised light is transmitted through plates of doubly refracting bodies, brilliant colours are observed. Certain substances have also the power of rotating the plane of vibrations of a polarised ray of light, so as to produce very beautiful effects. Sometimes the plane of polarisation revolves from left to right (like the hands of a clock), in others, from right to left. Among organic substances which rotate the plane of polarization to the right, may be mentioned, cane sugar, glucose, diabetic sugar, milk sugar, quinidine, narcotin, croton oil, &c.; and to the left, starch, albumin, quinine, strychnine, morphine, &c., &c. This kind of polarisation is called *rotatory polarisation.*

Chemical action of Light.—Many substances undergo chemical changes when exposed either to the light of the sun or to artificial light; the changes thus effected, are said to be chemical action induced by light. An instance of this is seen in the remarkable power plants possess of decomposing, by the aid of sun light, carbonic acid gas into its constituent elements, carbon and oxygen. It has been found, that the violet or most refrangible rays, and those rays beyond the violet, on which depend the phenomena of fluorescence, possess this power to a greater degree than the red rays, which are heat-giving rays.

Theory of the relation between heat and light.—This theory supposes that the particles of all bodies are in a state of constant motion, and the intensity and rapidity of this motion produces in the etherial medium surrounding them more or less rapid undulations which affect our senses. In proportion to the rapidity and intensity of these undulations, our minds experience the sensation of heat alone, or of heat accompanied by light. When a body is heated, molecular movements occur, and it first gives out heat without light; at a certain temperature, the vibrations are so rapid as to produce in our minds, through our organs of vision, the sensation of red light; and at still higher temperatures, the vibrations are still more rapid, and we have the sensations of yellow and blue light. These sensations of red, yellow, and blue light we unite synthetically by an unconscious process, and the sensation of white light is the result.

Phosphorescence.—When the particles of a body vibrate so that they emit light without a perceptible amount of heat, probably owing to slow chemical action, the body is said to be *phosphorescent.* This phenomenon received the name of phosphorescence, because phosphorus, in a state of slow combustion, emits vapours which shine in the dark with a faint blue light; hence the term has been employed to all bodies shewing a similar luminosity. Some minerals, such as native tricalcic diphosphate, or *phosphorite*, when gently heated, emit light, which soon ceases, and cannot be renewed until the body has been exposed to sunlight. Dead wood, putrid sea fish, various flowers of living plants, such as those of *Calendula officinalis*, and *Papaver orientale*, and *Rhizomorpha subterranea*, a plant found in mines, all exhibit phosphorescence under certain circumstances.* It is also shewn by many living animals, as by the glow-worm (*Lampyris noctiluca*) and fire-fly (*Elater noctilucus*), and also by many small crustacea, medusæ, polypora, and infusoria, which illuminate the sea at night. Phosphorescence may be produced artifically by heat, by the electrical discharge, by mechanical action, and by exposure to the sun's rays.

9. PROPERTIES RELATING TO MAGNETISM.—The native black oxide of iron (Fe_3O_4), mineral loadstone, possesses at certain parts of its surface, termed *poles*, the property of attracting small pieces of iron. This peculiar property was well known to the Grecian philosophers, and they gave to the ore the name of *magnetes*, from a village near which it was found. Hence the terms *magnet* and *magnetism.*

Magnets.—These are either natural or artificial. They are natural when composed of the ore or mineral just mentioned; they are artificial when made of iron or steel, to which the magnetic property has been communicated from a natural magnet. When a bar of steel is rubbed along its surface in a constant direction with the pole of a natural magnet, it becomes itself a magnet, attracts iron, and imparts its property in a similar manner to other bars of steel. A bar of steel or soft iron is also converted into a magnet, while a current of electricity is passed along a wire coiled round it.

Direction of a freely suspended magnet.—When a small magnetic needle is hung by a thread attached to its centre of gravity, so that it can move freely in a horizontal plane, it always takes up a particular position, one end pointing towards the north, and the other to the south pole of the earth. The two ends of the bar are accordingly termed the *north* and *south poles* respectively. A magnetic needle also takes up a particular position with reference to the horizon. This position is termed the "dip" of the needle. At the equator, the needle is horizontal; in the northern hemisphere, the north pole of the needle dips, and in the southern hemisphere the south pole dips. The cause of these attitudes of the suspended needle is, that the earth is a great magnet, the northern hemisphere exhibiting southern, and the southern hemisphere northern, magnetic polarity.

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* Balfour's Botany, vol. ii. p 674.

Magnetic attraction and repulsion.—If to a freely suspended magnetic needle another magnet is presented, it will be found that the south pole of the one attracts the north pole of the other, but repels the south, while the north pole attracts a south pole, but repels a north. Hence, the general law is, "*Similar magnetic poles repel, dissimilar poles attract each other.*"

Magnetic induction.—When a piece of unmagnetised iron is attracted by a magnet, it becomes itself a magnet by what is termed *induction.* The north pole of the magnet converts the end of the iron nearest to it into a south pole, and *vice versa.* This explains why a magnet in the form of a horse-shoe is stronger than a bar magnet of the same size. When a horse-shoe magnet attracts a bar of iron, the north pole of the magnet is attached to the south pole of the bar of iron, and the south pole of the magnet to the north pole of the bar of iron. Thus the piece of iron will be held with greater force than it would be by either of them alone.

Constitution of Magnets.—A magnet may be conceived as being made up of a number of hypothetical molecules, each having a north and a south pole, and all the similar poles pointing the same way (Plate VIII. fig. 27). In a row of such molecules, the opposite polarities towards the middle of the series neutralise one another, and thus magnetic action is perceptible only at the poles.

Ampère's theory of Magnetism.—Ampère's theory is that the phenomena of magnetism depend on currents of electricity circulating round the molecules of a magnet, moving parallel to each other, and in the same direction so as to represent a single spiral current. He was able to shew all the phenomena of magnetic action in a helical arrangement of conducting wires.

Electro-magnetic Rotation.—In 1821, Dr Wollaston surmised, and in the same year, Faraday, then assistant in the Royal Institution of London, demonstrated by experiment, that a wire, conducting a current of electricity, could be made to rotate round a magnetic pole, and conversely, that a magnet could be made to rotate round a conducting wire.*

Magnetism and Diamagnetism.—Up to the year 1845, when Faraday made his discovery of the universality of magnetic action, and of diamagnetism, it was supposed that magnetism was peculiar to a small number of bodies. Faraday then found that all bodies are subject to magnetism, but are not all affected by it in the same way. He divided substances into two great classes—the *paramagnetic* and the *diamagnetic*. All paramagnetic (πάϱα, by the side) bodies are attracted by either pole of a magnet, and when suspended over the poles of a horse-shoe magnet, point *axially*, that is, in a straight line between them. See Plate VIII. fig. 28, where N S is a powerful electro-magnet, firmly fixed in a wooden support. A B is a thread of silk suspending the substance to be examined. When a current of electricity is passed along the wires C Z, the apparatus becomes powerfully magnetic. The bodies belonging to this class are mostly metallic, viz., iron, nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum, and osmium.

The second or diamagnetic (διὰ, across) class of bodies includes all organic and inorganic substances which do not belong to the magnetic class. When a magnetic body is suspended over the poles of a powerful horse-shoe magnet (Fig. 28), it places itself *equatorially*, that is, *at right angles* to the straight line joining the two poles, because it is probably *repelled* by the poles. All animal textures and the entire body of a living animal are diamagnetic. Physicists have not yet agreed upon a satisfactory theory of diamagnetism.

10. Properties relating to Electricity.—More than two thousand years ago, a Grecian philosopher, Thales, observed that when amber was rubbed with silk it had the power of attracting certain bodies; and he ascribed the influence to an inherent soul which, stirred up by friction, went forth and drew the particles to itself.† The Greek word for amber is ἤλεκτϱον; hence our modern name *electricity*.

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* Faraday. Life and Letters. By Dr Bence Jones. Vol. I. p. 338.

† Ganot's Physics. *Op. Cit.*

Nature of Electricity.—Electricity is a powerful physical force inherent in all bodies, and evolved from them by friction, chemical action, heat, magnetism, vital changes, and by all kinds of motion. Various theories of electricity have been advanced; but three are of chief importance, viz., those of (1) Franklin, (2) Dufay and Symmers, and (3) the dynamical theory.

(1) *Franklin's, or the one fluid theory.*—He supposed that in all bodies there existed a subtle fluid which repelled its own particles. When any body contains its own definite amount of this fluid, it is a *state of equilibrium;* when a body has more than its proper amount of the fluid, it is *positively* electrified; when less, *negatively* electrified.

(2) *Dufay and Symmer's, or the two fluid theory.*—This theory states that there are two fluids, the *positive*, or *vitreous*, and the *negative*, or *resinous.* When they are combined, they neutralise each other, and the body is in its natural condition. When there is excess of positive fluid, the body is *positively* electrified; when there is excess of negative fluid, it is *negatively* electrified. A negative fluid always repels a negative fluid; and a positive repels a positive; but a negative attracts a positive, and a positive a negative. This theory has been generally accepted until recent times.

(3.) *The Dynamical Theory.*—Electricity, according to this theory, like heat and light, is *a mode of motion.* There is an etherial medium filling up the interval of bodies and pervading space, and the phenomena of electricity are due to peculiar vibrations of this medium. One kind of these vibrations may produce heat, another light, and a third kind may constitute the phenomena we include under the term electricity.

Conductors and non-conductors.—Electricity passes easily through or along the surface of some bodies, but other bodies offer resistance to its passage. When electricity passes through or along the surface of a body without much resistance, it is called a *conductor.* When a substance offers resistance to the passage of electricity, it is termed a *non-conductor* or *insulator.* The following is a list of conductors arranged according to their conducting power, the best conductors being placed first: the metals, charcoal, dilute acids, saline solutions, animal fluids, living animals.

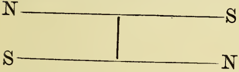
The metals vary greatly in conducting power. The best conductor is silver, next copper, gold, sodium, calcium, potassium, iron, tin, platinum, lead, mercury, bismuth, and the worst conductor of all is tellurium.

As examples of electrical non-conducting substances may be mentioned caoutchouc, porcelain, dry paper, wool, hair, feathers, silk, glass, wax, sulphur, resin, amber, and shellac. Gutta-percha possesses great insulating power.

Induction.—The action of an electrified body on others near it is termed *induction* or *action at a distance.* When a conductor, A, is placed near an electrified body, B, A becomes charged with the opposite kind of electricity to what it had before, and, if moveable, is *attracted* towards B. If both A and B are conductors, and are brought into contact, the moment they do so, the two electricities combine, and both bodies becoming similarly electrified, A and B *repel* each other. Upon these phenomena of attraction and repulsion, are constructed almost all the instruments for ascertaining the nature and intensity of the electricity with which a body is charged. Such instruments are termed *electroscopes.* The ordinary gold leaf electroscope (Pl. VIII. fig. 32) consists of a glass bottle having attached to its neck by gum mastich, a brass tube closed at the top by a thick brass plate. To the brass plate is a wire coated with shellac, and to the lower end of this wire are two strips of gold leaf of about an inch in length. Facing these gold leaflets on the exterior of the bottle, are pieces of tinfoil. When a body positively electrified is brought near such an apparatus, the leaflets at once diverge, often with such force that they are in danger of being torn.

Detection of electrical currents.—Professor Oersted of Copenhagen, in the year 1820, discovered that, when a magnetic needle is suspended or carefully balanced in the magnetic meridian, under or above and parallel to a wire conducting a current of voltaic electricity, the needle immediately tends to place itself at right angles to the wire. This experiment was the origin of *electro-magnetism.* An arrangement is shewn in Pl. VIII. fig. 31 for illustrating this fact. Let N S be a needle freely balanced on W S, and A B a wire conducting a current from C to Z in the direction of the arrows. If N S is placed on the magnetic meridian, and a current of electricity is sent from C to Z, the magnetic needle, N S, will immediately move so as to place itself as near as may be to a right angle to the wire, A B. In the same year, Schweigger, a German philosopher, applied this discovery of the action of a conducting wire on a magnetic needle to the construction of an instrument for shewing the direction and measuring the intensity of voltaic currents. This instrument is termed the *galvanometer.* It consists of a coil of wire, insulated by being covered with silk, in the centre of which is suspended, by a very delicate filament of silk or cobweb, a magnetic needle. Above the coil there is a card graduated into 360 degrees. On passing even a feeble current along the wire, the needle is at once deflected. Nobili greatly improved the galvanometer by introducing the astatic needle.

The astatic needle of Ampère.—As a magnetic needle always points to the north pole of the earth, it is evident that before using the galvanometer as at first constructed, the coil of wire must be placed parallel to the needle that is pointing north and south. To obviate this inconvenience Nobili made use of the astatic needle of Ampère, which consists of two needles instead of one, connected together by a bit of straw or a fine piece of tortoiseshell so that the north pole of the one is over the south pole of the other, and *vice versa.* Such an arrangement constitutes an *astatic system*, and as the one needle neutralises the other, both, when suspended, are liberated from the static action of the earth, and swing freely in any direction. In most galvanometers, however, a small magnet is placed so as to keep the needle parallel with the coil.



The multiplying Galvanometer.—By increasing the number of coils, the galvanometer becomes more sensitive, and indicates, by a deflection of the needle, even the weakest currents. The reason of this is, that the action of the wire above and below the needle tends to move it in the same direction, and thus every additional coil multiplies the electromagnetic action, and produces a greater and greater deflection of the needle. The most delicate galvanometer yet constructed for physiological use, is that of Du Bois-Reymond, the Professor of Physiology in Berlin, in which the wire is about 16,752 feet long, and forms 30,000 coils round the needle. Sir William Thompson, of Glasgow, has devised a galvanometer of less bulk, in which there is a small vertical mirror fixed to a light astatic needle suspended by a short thread. The mirror reflects upon a graduated scale the ray of light from a lamp carefully adjusted before the apparatus, and thus the slightest movements of the needle are apparent. More recently, Sir William has invented a self-recording galvanometer, but it has not yet been used in physiological research. (See Practical Physiology.)

Modes of producing electricity.—These may be classified as follows:—1. by friction (*frictional electricity*); 2. by heat (*thermo-electricity*); 3. by chemical action (*Galvanic* or *Voltaic electricity*); 4. by induction (*Faradic electricity*); and, 5. by living organised structures (*organic electricity*).

1. *Electricity produced by friction.*—The simplest instance of this is the electricity produced by rubbing a glass rod or a stick of sealing-wax with a piece of flannel. Such a rod, when brought near a gold leaf electroscope, immediately causes the strips of gold leaf to diverge. The action of the ordinary electric machine is founded on the excitation of electricity by friction. This mode of producing electricity is not of much service in physiological research.

2. *Electricity produced by heat.*—When two pieces of different metals are soldered together, and heat is applied to the point of junction, an electric current is established, when the point of junction is brought to a temperature different from that of the rest of the circuit. The strongest current of this kind is produced by a circuit of bismuth and antimony. Such a combination of two metals is called a *thermo-electric pair*, and a number of these pairs placed together constitutes a *thermo-electric battery*, *chain*, or *pile*. An apparatus of this kind is termed *Melloni's pile*. Thermo-electric arrangements have been successfully used by Becquerel and Breschet* in the investigation of animal heat. (See Animal Heat.)

3. *Electricity produced by Chemical Action.*—This is the most important of all sources of electricity, and is the basis of the ordinary voltaic battery. When a system of two dissimilar metals is immersed in a fluid, which acts on one of them, a current of electricity is produced, and we have what is called a *galvanic* or *voltaic couple*. The chemical and other phenomena occurring in a voltaic couple, will be readily understood by referring to Plate VIII. fig. 29. In the glass vessel there represented, partially immersed in dilute sulphuric acid, are two metallic plates, the one, Z, being a plate of zinc, the other, C, a plate of copper. When these two plates are not in contact, little or no action takes

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* Becquerel and Breschet, "Memoir sur la chaleur Animale."—*Annales de Chimie et de Physique*, tome lix. p. 113. 1835.

place, except the formation of a few bubbles of gas on the zinc; but the moment they are allowed to rest against each other, as shewn in the figure, the surface of the copper becomes coated with minute bubbles, which increase in size, and eventually escape into the air. The whole of the liquid in the neighbourhood of the copper soon assumes a state of effervescence, while that around the zinc is free from disturbance. The copper is not acted on chemically, but the zinc is being dissolved. The zinc plate decomposes the film of water on its surfaces ; oxide of zinc (ZnO) is formed, which is rapidly dissolved by the sulphuric acid, forming zinc sulphate ($ZnSO_4$), thus leaving a clean surface of zinc for another film of water, and so on. The other element of water, the hydrogen, passes over to the copper plate, and appears there in the form of the bubbles just described. But the chemical action or force which has divided water into its elements, becomes another form of force, called *electrical force.* A current of electricity has been set up ; starting from the zinc plate, it passes to the copper, and proceeds up the copper to the zinc plate again, as indicated by the arrows in the figure.

The metal most attacked by the liquid in a voltaic couple, is called the *positive,* the other the *negative* metal. In the arrangement just described, the zinc is the positive, and the copper the negative, elements. The part of the metal immersed in the fluid, is termed the *plate,* and the part out of the fluid is the *pole* or *electrode.* As the current always travels in the fluid from the positive plate, where there is the greatest chemical action, to the negative plate, where the action is the least, the positive *pole,* which is out of the fluid, is connected with the *negative plate,* and *vice versa.* Instead of the term pole, the word *electrode* was used by Faraday, and he expressed the emitting or positive electrode, by prefixing the syllable *an,* and the receiving or negative, by prefixing the syllable *cath.* So that, according to this nomenclature, the upper end of the positive element is the *anelectrode* (’ανὰ, up ; ἤλεκτρον, electricity ; ὁδὸς, a way), and the upper end of the negative element, the *cathelectrode* (κατὰ, down ; ἤλεκτρον ; ὁδὸς).

The following is a list of metals arranged according to their electrical behaviour, the electro-positive being placed at one end, the electro-negative at the other. Hence, if any two of these are placed in contact in dilute acid, the current in the connecting wire, out of the fluid, proceeds from the one lower in the list, to the one higher :—zinc, silver, tin, gold, iron, platinum, copper. In the fluid, the current passes from the one higher in the list to the one lower.

Volta's Pile.—This apparatus, invented by Volta, consists of plates of copper and zinc of equal size, arranged, along with pieces of thick flannel, in the following order :—1st. A plate of copper; 2d. A plate of zinc; 3d. A piece of flannel moistened with dilute acid, or a strong solution of common salt; then a plate of copper, then zinc, then flannel, and so on, until a pile is formed. Such an arrangement will yield a large quantity of electricity of low tension. It is never used for physiological research.

Voltaic Batteries.—Voltaic *couples* or *elements* may be united together to form a *battery* in two ways. When all the positives are united on one side, and all the negatives on the other, a battery is made which is capable of generating a large amount of electricity, but electricity having a low tension, or, in other words, a weak power of overcoming resistance. If, on the other hand, it be desirable to give to the current of electricity evolved from any battery a high tension, then the positive pole of one couple must be united with the negative of the next, and so on through the entire series employed. In arranging a series of couples to form a battery of high tension electricity, care should be taken to use batteries whose negative elements are of equal size, as the absolute power of any galvanic arrangement, *cæteris paribus*, depends on the area of the surface of the negative element.

Various batteries or couples are useful in physiological research, but the following are the most important,—

1. *Daniel's Battery.*—This consists of a porcelain or copper vessel containing a saturated solution of sulphate of copper ($ZnSO_4$). Inside the cylinder, is a thin porous vessel of earthen ware, containing a strip or roll of amalgamated zinc immersed in a solution of salt ($NaCl$) or dilute sulphuric acid (7 of H_2O to 1 of H_2SO_4). The action of this kind of battery is constant, because the chemical decomposition which takes place produces a continual deposition of metallic copper, whereby its surface is always kept pure. It also gives a current of considerable intensity. The negative pole in this battery is connected with the zinc (positive plate), and the positive pole with the copper (negative plate), and the current travels, in the fluid, from the

zinc to the copper, and out of the liquid, from the copper to the zinc.

2. *Bunsen's Battery.*—Each element consists of a bar or roll of compact charcoal or coke immersed in a porous earthenware vessel containing strong nitric acid (HNO_3). Round this is a hollow cylinder of amalgamated zinc immersed in dilute sulphuric acid (1 H_2SO_4 to 7 of H_2O), to which is fixed a strip of copper. The upper part of the bar of carbon is fitted with a binding screw serving to connect it with the zinc of the next couple. The positive pole proceeds from the carbon (negative plate), and the negative from the zinc (positive plate). The current travels in the fluid from the zinc to the carbon, and out of the fluid from the carbon to the zinc. This is a most energetic battery.

3. *Grove's Battery.*—In this battery the positive plate consists of a large surface of amalgamated zinc immersed in dilute sulphuric acid (1 of H_2SO_4 to 10 of H_2O), and the negative plate consists of a small strip of a platinum immersed in strong nitric acid (HNO_3). Each zinc plate is coiled round a porous earthenware vessel containing the platinum. The positive pole in this case proceeds from the platinum (negative plate), and the negative pole from the zinc (positive plate). In the fluid, the current travels from the zinc to the platinum, and out of the fluid from the platinum to the zinc. This battery is powerful, but not very constant, and after it has been in action for an hour, copious red fumes of the lower oxides of nitrogen are given off, which render it disagreeable.

4. *Smee's battery.*—This convenient form of battery consists of a sheet of platinum covered with finely divided platinum, or of a plate of platinised silver placed between two plates of amalgamated zinc. There is only one liquid required, dilute sulphuric acid (1 of H_2SO_4 to 7 of H_2O). The negative pole in this couple proceeds from the zinc (positive plate), and the positive pole from the platinum (negative plate). The current therefore travels in the liquid from the zinc to the platinum, and out of the fluid from the platinum to the zinc. The convenience of having to use only one acid (H_2SO_4) in this form of battery is very great, and it gives a tolerably constant current, which, however, unfortunately tends to become weaker and weaker, in consequence of the destruction of the zinc plate.

Electrical forceps, made of coils of zinc and copper moistened with acetic acid, are of great service in physiological experiments.

Another form of battery has lately been introduced. It consists (Plate VIII. fig. 30*a*) of a glass bottle containing a strip of zinc (positive plate) having on each side of it a thin slip of carbon (negative plate) immersed in a saturated solution of bichromate of potash ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) in the proportion of twelve parts of the former to one part of the latter. This is an energetic battery, constant for a few hours, and when not in use, action may conveniently be stopped by drawing out the zinc plate.

Physiological action of the galvanic current.—When the electrodes of a powerful battery are held in the two hands, a strong shock is felt, which is more violent in proportion to the number of couples used. The shock of a single couple is not felt in the hands, but if the terminals are applied to the lips or the mucous membrane of the mouth, or the tongue, a burning sensation and peculiar taste are perceived. When the terminals of a strong battery are applied to the body of an animal recently killed, such as a frog or rabbit, the muscles powerfully contract. In 1819, Dr Ure* experimented on the body of a man who had been hanged, with a like result. The electric current in a healthy individual produces two sensible effects, pain and muscular contractions. When applied to a nerve, it excites the nervous force which, by propagating itself to muscles, produces in them contraction, and by transmitting an influence to the cerebrum produces the sensation of pain. But the muscular contractions, and the painful sensations, are produced only at the moment of opening and closing the current.

Thermal and luminous effects of the galvanic current.—When a strong current is transmitted along a metallic wire, the wire becomes heated, and incandescent if short and thin. This may be readily demonstrated by connecting the two terminals of a powerful battery by a thin piece of platinum wire. In a few minutes, the wire becomes red-hot. A useful application of this fact is seen in the surgical appliance called the electro-cautery, by means of which the surgeon may readily remove polypi without hæmorrhage. When the electrodes of a voltaic battery are brought into contact, a brilliant spark is observed. When a large number of cells are used, and the two wires terminate in pencils of charcoal, a magnificent electric light is obtained. Davy made the first experiment of the electric light in 1801, by means of a battery of 2000 plates, each four inches square.* The electric light has similar properties to solar light.

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* Ure. *Ann. de Chim. et de Phys.* tom. xiv. p. 367.

Chemical effects of the galvanic current.—When an electrical current is passed through water, the latter is decomposed into its two constituent gases, oxygen and hydrogen. This process is called electrolysis (ἤλεκτρον, electricity ; λύσις, disintegration). In electrolytic decompositions, one of the elements goes to the positive pole, the other to the negative. The bodies separated at the positive pole, are called *electro-negative* elements ; those separated at the negative pole, are called *electro-positive* elements. The same body may be electro-negative or electro-positive. For example, sulphur is electro-negative to hydrogen but electro-positive to oxygen. When the terminals of a battery are dipped into living blood, a clot of fibrin soon collects around the positive pole and bubbles of oxygen arise from the negative pole. This action suggested to surgeons the operation of galvano-puncture, first proposed by M. Prevaz† in 1833, by which the fibrin is coagulated within an aneurismal sac.

4. *Electricity produced by induction.*—Electricity produced by induction, or by action at a distance, is called *Faradic electricity*, in honour of its discoverer, Faraday, who first investigated this form of electricity in 1832. The method of producing this form of electricity will be readily understood by referring to figure in Plate VIII. fig. 30.‡ Let A and B be two wooden pillars firmly fixed in a strong piece of wood. In the top of each of these pillars are two binding screws, by means of which the bent wires, C D and E F, may be attached, one below the other, and about half an inch apart. The galvanometer G is connected with the two inner screws, E F, and one of the outer binding screws, D, with the negative pole of the battery H. There are now two distinct circuits. The one, E G F, includes the galvanometer G, the other consists of the battery A and the wire C D. This last circuit is not yet complete, for the wire C is not connected with the positive pole of the battery. Place the galvanometer so that the needle will be parallel with the wire E F. If the battery circuit be now completed by simply *touching* the positive pole

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* Ganot's Physics, *Op. Cit.*

† Prevaz, *Comptes Rendus*, tom. xxi. p. 992.

‡ Intensity Coils. Dyer. London. 1866.

with the wire from the binding screw C, the needle of the galvanometer will be at once deflected.

This deflection of the needle is caused by a current of electricity passing along the circuit E G F, and as this circuit has no connection with the battery circuit C D H, the current in E G F was *induced* by the current passing in C D H. A current in the galvanometer circuit has been set up by the current in the battery circuit. But if we now *fix* the wire C to the binding screw on the positive pole of the battery, the needle at once returns to its original position, and is quiescent. Separate the wire, and the needle will be again deflected by an induced current, but this time in the opposite direction. The induced current in the galvanometer circuit E G F is, therefore, produced only at the moment of opening and closing the battery circuit C D H. When the battery circuit is closed, a current is produced in the galvanometer circuit in an opposite direction to that in the battery circuit; but when the battery circuit is opened, the current in the galvanometer circuit is in the same direction as that in the battery circuit.

When two coils of wire are used instead of a single wire, as in the experiment just described, a very powerful current is induced in the one at the moment of opening and closing the electrical current in the other. The coil through which the current passes from the battery is termed the *primary coil* (E D H), the coil in which the current is induced, has received the name of the *secondary* coil (E G F). Induced currents are also formed when a primary coil traversed by a current is approached to, or removed from, a secondary one. When the latter is brought near the former, a current is induced in the first in an opposite direction to that of the second; but when a secondary coil is removed from a primary, a current is induced in the secondary in the same direction as that in the primary.

Induced currents may also be obtained by the action of magnets. This kind of electricity is sometimes called *Magneto-electricity.* A current of electricity passed round a bar of soft iron converts it into a magnet, a fact first observed in 1837 by Sturgeon; in like manner, when a magnet is thrust into a coil of soft iron wire, a current of electricity is induced in the coil (Faraday).

The phenomena of induction has given rise to the construction of instruments capable of producing a series of induced currents by rapidly breaking and forming the circuit in a primary coil of wire. These instruments are termed *Ruhmkorff's coil*, *induction coils*, *magneto-electric machines*, &c. A description of these, and of their use in physiological investigation will be given under Practical Physiology.

Variety of currents.—By a *continuous* current is meant a uniform flow of electricity proceeding in a stream from any number of galvanic elements; by an *interrupted* current, one that is broken or interrupted, and then re-formed; and by an *induced* current, a current obtained by an induction apparatus in the manner already described. The physiological properties of each will be referred to under Practical Physiology.

5. *Electricity produced by living organised structures* (ORGANIC ELECTRICITY).—Organised beings, as masses of mere matter, are subject to the laws which determine electrical equilibrium and electrical disturbance. But the physiological changes which occur in the tissues of a plant or animal cause electrical disturbance, and thus give rise to currents. The investigation of these phenomena has received the name of *electro-physiology*, a department of science which, in late years, from the unremitting labours of the German school of physiologists, has made remarkable advances. It may be subdivided into (1) electricity in plants and vegetable tissues (Vegetable Electricity); (2) electricity in animals and in the animal tissues (Animal Electricity).

1. *Vegetable electricity in plants.*—(VEGETABLE ELECTRICITY.)—No definite results have been obtained as to electrical phenomena in plants. Buff* has shewn that the roots and central parts of plants are negative to the humid surface of the leaves, flowers, fruit, and young branches; but this condition is probably due to ordinary chemical reactions, and not dependent on vital causes.

2. *Electricity in animals and in the animal tissues.*—(ANIMAL ELECTRICITY.)—This includes a description of electrical phenomena in certain fishes, and in the animal tissues such as muscle, nerve, &c.

ELECTRICAL FISHES.

Certain fishes have special organs for the development of electricity, by means of which they have the power of communicating a shock to other animals, a power they use either for self-defence or for paralysing their prey. The most remarkable of these fishes are :—

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* Buff, *Ann. Chim. Phys.* [3] xli. 198.

1. *The Torpedo.*—This fish, a species of ray, termed by naturalists, *Torpedo Galvani*, after the celebrated Bologna professor, is a native of the Mediterranean. It is sometimes found in the Atlantic, rarely in the North Sea. Its powers of giving benumbing shocks was recognised by fishermen before the days of Aristotle, who carefully describes them. J. Walsh* was the first, in 1773, to shew experimentally that these shocks of the torpedo were essentially electrical. The electric organs, two in number, are large, flat, kidney-shaped bodies, placed on each side of the head and gills. The organ is composed of a mass of hexagonal prisms, placed vertically between the dorsal and abdominal integument, and each prism is divided by a series of delicate membranous plates or diaphragms attached by their angles to the aponeurotic sheaths separating the prisms. The plates are separated from each other by a jelly-like albuminous fluid. In each electric organ there are from 400 to 1000 prisms, and it has been estimated that there are about 2000 plates in each prism. This powerful electric battery, thus divided into compartments, is richly supplied with large nerves. These are (1) a large branch from the trigeminal, and (2) four branches from the vagus,† which spring from a large trunk on each side of the fore part of the medulla-oblongata. According to Paccini,‡ the nerves enter the laminæ at their points of attachment to the prisms, and are distributed to their under surface, and in the fluid between that surface and the next lamina. They ramify here in a very vascular nucleated tissue. The upper or dorsal surface of the diaphragm is negative, while the under surface, on which the nerves are distributed, is positive. Each prism is thus analogous to a voltaic pile. In the torpedo the piles are vertical, and the plates horizontal.

2. The *Gymnotus electricus* is an eel-like fish common in the lakes and rivers of South America, especially in Guiana. It possesses four electric organs, two on each side, stretching from the pectoral fins to near the end of the tail. The proportional size of the electric organs to the body is much

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* Walsh. *Phil. Transactions* for 1773.

† Owen, Anatomy of Vertebrates. Vol. i. p. 350-2.

‡ Paccini, Sulla struttura intima dell'organo elettrico del Gymnoto. 1852.

greater in the gymnotus than in the torpedo, the viscera of the animal occuping only a small portion of the anterior part of the body. Each electric organ consists of a series of horizontal membranes or plates arranged in the longitudinal axis of the body nearly parallel to each other. The organ thus resembles a series of galvanic troughs. Each trough is divided by thin vertical laminæ or diaphragms. Each lamina is not simple, as in the torpedo, but, according to Paccini,* it consists of two layers separated by a fluid. The posterior layer is a delicate fibrous structure, and in it alone the nerves ramify. It is the positive element of the battery. The anterior is composed of vascular nucleated tissue, and it is the negative element. The fluid between the two layers of the laminæ differs in character from that in the interspace between the posterior layer and the anterior of the next laminæ, but both fluids are of an albuminous character. The electric battery of a gymnotus, therefore, does not resemble a voltaic pile, with one liquid, but a voltaic battery with two liquids. In the gymnotus, the batteries are horizontal and the plates vertical, the opposite arrangement to that described in the torpedo. The electric organs are richly supplied by the abdominal branches of the spinal nerves, and it is remarkable that they receive no branches from the trigeminal and vagus which supply those of the torpedo.†

3. The *Malapterurus electricus*, Raasch, or thunder-fish of the Arabs, is a native of the Nile, Niger, and other African rivers. The electric organ forms a layer beneath the skin enveloping the whole body with the exception of the head and fins. An insulating layer of fat separates it from the subjacent muscles. The laminæ are traversed by numerous very delicate decussating membranes which divide it into lozenge-shaped cells filled with an albuminous fluid. A large nerve trunk from the commencement of the cord supplies the organ. This is distributed to the abdominal or posterior surface of electrical laminæ, forms a conoidal expansion, and then pierces the centre of the plate, distributing its branches to the thoracic or anterior surface, which is the positive one.‡

4. In addition to these, the *Mormyrus longipinnis*, a fish allied to the pike family, found in the Nile; the *Rhinobatus electricus*, a

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* Paccini, *Op. Cit.*

† Owen, *Op. Cit.*

‡ Max Schultze Zur Kenntniss der Electric. Org. I. Malapterurus, &c. Halle. 1858, s. 14, Taf. i. figs. 1, 2, 3.

ray from Brazillian waters ; the *Tetraodon electricus*, a species of globe-fish inhabiting the Nile ; the *Gymnarchus electricus*, an eel also found in the Nile ; and, the *Trichiurus electricus*, a ribbon-like fish found in the Indian Ocean, are said to possess electrical properties, but not to the extent manifested by the three fishes we have more particularly described. In the common skate, *Raia batis*, there is an organ, first described by Dr Stark in 1844, and afterwards by Robin,* which structurally resembles a voltaic pile, but its electro-motor power has never been tested.†

General properties of electric fishes.—The electricity generated by these fishes has considerable tension, and is capable of developing the electric spark, of magnetising steel, of decomposing iodide of potassium, and of affecting a galvanometer.‡ In order to receive a shock, an animal must be in communication with the electric fish at two points, so as to complete the circuit, but the circuit may be completed by the earth. According to Matteucci and Savi,§ an insulated frog's leg does not contract when the extremity of the nerve attached to it is brought into contact with a torpedo, but the instant a second point of contact is made, powerful contraction ensues. Matteucci also found that while the electric organ was in operation no current traversed the nerves. According to Bilharz,|| the nerves are always distributed to the positive side of the electrical plate, a law which anatomical research has fully confirmed. Thus in the *torpedo* the electric current passes from the belly to the back ; in the *gymnotus* it passes from the tail to the head, and the most powerful shock is experienced on grasping the head with the right hand and the tail with the left. As the hands are approximated, the shock becomes weaker. In the *malapterurus* the current flows from the head to the tail. The gymnotus transmits a more powerful shock than the torpedo, and Humboldt¶ states that so powerful an animal as the horse may be killed by a full grown gymnotus.

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* Robin. Robin's *Journal de l'Anatomie.* September 1865.

† John Goodsir, "Anatomical Memoirs," vol. ii. p. 295.—Max Schultze, *Reicherts' Archiv.*, 1858.

‡ Faraday, "Experimental Researches in Electricity," Ser. xv. Du Bois-Reymond.—*Monatsb. des Berlin akad.* 1861. P. 1105.

Matteucci and Savi, "Traité des Phénomènes Eléctro-Physiologiques." 1860.

|| Bilhartz. Uber der elektr. Organ der Zitterwelses, &c. Leipsig. 1857.

¶ Humboldt and Bonpland, "Voyage Zoologique." 1811.

The phenomena manifested by electric fishes are of great interest, because they afford an instance of the relation existing between vital and physical forces. That the organs can develope electricity to a considerable amount only when provided with a proper nervous supply, is proved by the fact that when the nerves are divided no shock is transmitted, but on irritating the distal end of the nerve, the electric discharge is at once felt. Matteucci,* however, states that when a fragment of the electric organ of a torpedo was brought into connection with a galvanometer, the needle was deflected to an angle of from twenty to thirty degrees, indicating that, for a time, the electric organ retains a portion of its activity even after all nervous and vascular connection had been severed. The nerve influence, transmitted from the nervous centres of the animal, probably excites, in some way or other, nutritive changes in particular portions of the battery, electrical disturbance is thus occasioned, and a current passes through the structure. This is produced, according to Du-Bois Reymond, by the same polar action as exists in muscles. As the battery in all electrical fishes is imperfectly insulated, being surrounded by water—a good conducting medium—a large quantity of electricity is lost by diffusion, but so much electricity is evolved that the animal can afford to lose a proportion of it. When, as a result of irritation, a torpedo sends a shock to the body of an animal, the mechanism of the act is that of a reflex or diastaltic action (see Reflex Action); and it is confirmatory of this view, that such a poison as strychnia, which excites the reflex motor centres, causes the electric organs to emit a quick succession of involuntary electric discharges, a fact observed by Matteucci and Savi. But the action is also under the control of the will of the animal. On transmitting several powerful shocks the electric organ is rapidly exhausted, and the animal requires an interval of repose and nourishment to recover the loss of nervous energy it has sustained.

ELECTRICITY IN THE ANIMAL TISSUES.

The electrical phenomena manifested by living muscle and nerve have already been briefly referred to (pp. 82 and 97), and the methods of demonstrating these successfully will be fully explained in treating of Practical Physiology. As this subject is of great physiological interest, it will be instructive to trace briefly its rise in the end of the last century, and its progress since that time.

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* Matteucci. *Proceed. Royal Society,* x. 567.

The discovery of animal electricity dates from 1786. It is said that Madame Galvani, on preparing some frogs for culinary purposes, observed that the apparently dead animals became convulsed when brought into the neighbourhood of an electrical machine in action. Her husband, who was Professor of Anatomy and Physiology in Bologna, had his attention directed to these phenomena, and found that the convulsions occurred at the instant a spark was emitted from the conductor, provided some metallic substance was in contact with the nerve of the frog. He then tried the same experiment with lightning, and in the autumn of the same year he endeavoured to discover the action of atmospheric electricity on the prepared legs of a frog when the sky was stormless. On the 20th of September he suspended these frogs to the iron trellis-work surrounding the roof of his house, by means of copper hooks, and saw, when they were blown about by the wind, that convulsions were caused whenever they came in contact with the iron. This observation convinced him that an electrical machine was not required, the same effect being produced on the contact of dissimilar metals (Pl. VIII. fig. 33). He at length concluded that the convulsions were due to inherent electricity, that is, electricity seated in, and originating from, the animal tissues.

Galvani published an account of his experiments in 1791. At this time the existence of a "nervous fluid," a something which, if not life itself, was considered inseparable from it, was keenly debated by the learned, and contended for by the animists. Galvani's discovery, therefore, riveted the attention of ths scientific world—electricity took the place of the nervous fluid, and the entire source of life, as well as the origin of the bodily and mental functions, were now ascribed to the existence of a new principle, which, from the name of its discoverer, was called *Galvanism.*

Among the many distinguished men whose attention was attracted towards Galvani's discovery, the most remarkable was Alexander Volta. He was a physicist and professor of Natural Philosophy in the University of Pavia. At first he entered fully into the views of his countryman, and repeated his experiments. But in his hands, galvanism, instead of taking a physiological and medical, took a physical direction. Finding that muscular contractions in a frog could be produced only by the contact of dissimilar metals, he at length dissented from Galvani's theory of animal electricity. Trying by the same means to produce muscular contractions in the human body, he failed. But on placing a metal above and below the tongue, he detected a peculiar taste at the instant of contact. This experiment had been previously recorded by Sulzer, and laid aside only as curious, but in the hands of Volta it became the groundwork of chemical, or what has been called *Voltaic*, electricity. In opposition to Galvani, therefore, he put forth the opinion that the muscular contractions in the frog had nothing to do with animal, but were caused by a very feeble *artificial*, electricity, which was produced by the application of heterogeneous metals to the limbs of the animals.

In reply to this attack, Galvani pointed out that the contractions might be occasioned by one metal, but Volta then shewed that the two extremities or surfaces of one piece of metal might be in different states of tension, and therefore capable of exciting electricity. Galvani then used mercury alone, to which this objection could not apply, and dipping the muscles into one part of a trough filled with it, and the nerves into another, he thus succeeded in causing contractions. But Volta, by a new series of experiments, demonstrated that mercury was always altering under the action of the air, and that in conjunction with moisture, it could produce electricity independent of an animal. It now became necessary for Galvani to shew that contractions could be obtained without any metal at all, and, aided by his nephew Aldini, he succeeded in doing so, and, as he thought, in for ever silencing his formidable opponent. In fact he discovered that on dissecting out the crural nerve, but leaving one end in connection with the leg, and bringing this nerve in contact with the muscles externally, the latter were thrown into distinct contractions. He also caused the limb to contract by simply bringing the nerve in contact with the muscle of another animal insulated from the limb.

His theory of animal electricity now was, that it was produced in the nervous system, and especially in the cerebrum. The internal substance of nerves he considered to have great conducting powers, but their oily surfaces prevented dispersion through the body, and allowed its accumulation in the muscles. These last he compared to a Leyden jar, the outer surface being negative, the internal, positive. The nerve was analogous to the conductor of the jar. When the nerve connects the inner with the outer surface there is a discharge of electricity, causing irritation and contraction of the muscles.

Volta at first endeavoured to meet these facts by the supposition of a mechanical stimulation of the nerves, but at length shewed, that if not caused by metals, it was necessary that there should be dissimilar fluids and tissues which were capable of exciting electricity. It was admitted even by Galvani's followers that it was essential to the success of the experiment that the muscle with which the nerve was in contact, should be moistened with blood or some thick fluid, and if by any accident the limb remained motionless, it was only necessary, in order to induce muscular contractions, that the parts to be brought in contact, should be moistened with saliva, brine, mucus, &c., or still better, with soapy water, and best of all, with a strongly acid or alkaline fluid.

Galvani, in several letters to Spallanzani, endeavoured to weaken the force of these arguments, as did Humboldt, who shewed that contractions resulted when the circuit consisted only of nerve and muscle, without the interposition of blood, mucus, &c. (Pl. VIII. fig. 24). But about this time, 1798, Galvani fell ill, and died on the 4th of December of that year. Volta's experiments, on the other hand, were continued with unabated energy, and towards the end of 1799, he discovered the Voltaic battery, whereby his opinions, and the production of electricity by the contact of metals and a fluid, was completely proved. This great victory, which Galvani, by his death, escaped the mortification of experiencing, notwithstanding the support of Humboldt, Aldini, Pfaff, and a few others, overthrew the idea of an animal electricity for the space of twenty-eight years. During this period, indeed, its existence was generally regarded with incredulity ; and the term, *animal magnetism*, adopted by impostors, only tended to bring it still more into contempt. Volta died in 1826, and it is curious that only a year afterwards Nobili again revived animal electricity, by demonstrating the existence of an electrical current in the frog. In the interval of twenty-eight years, Voltaic electricity made the most wonderful progress. In the hands of Sir Humphrey Davy it led to the most brilliant discoveries in chemistry, and its subsequent applications to the production of motor power in various ways, and to communication between distant parts of the earth, constitute the wonders of physical science in the present age.

In 1820, Oersted, a Danish philosopher, discovered electro-magnetism. He shewed, as has been already explained (p. 148), that when a continuous galvanic current passes along a wire, placed above or below, and parallel to a magnetic needle, the latter is immediately deflected. This led Ampère to construct the astatic needle, as previously described (p. 149), and in turn, enabled Nobili to construct a galvanometer,* which he rendered exquisitely sensitive by various improvements. He prepared a frog after the method of Galvani, and having introduced its two legs into two glasses of salt water, he united the two vessels by filaments of moist cotton,—the frog's muscles at once contracted; removing the cotton, he connected the two glasses by means of the galvanometer circuit, and he observed a deviation of from 10° to 30°, shewing that *an electrical current was passing from the feet to the head of the animal.* By introducing several frogs into the circuit, he increased the strength of the current. The galvanometer of Nobili enabled physiologists to demonstrate that Galvani and Volta were both right and both wrong. Galvani was right in maintaining the existence of an inherent animal electricity, whilst he was wrong in supposing that the contact of two metals with the tissues was a proof of this. Volta, again, was right in maintaining that galvanism could be produced independently of animals, but wrong in denying that electrical currents existed in them. By the astatic needle, as Du Bois-Reymond happily remarks, metallic electricity was enabled to atone for the wrong she had done to her more tender twin sister in their earlier years.

Whilst Nobili, by his construction of a galvanometer, was of such essential service, he was led into an error, viz., that the deflection of the needle was due to thermo-electricity. It was ten years later, in 1837, that Professor Matteucci, of Pisa,† shewed, that to obtain a deviation of the galvanometer needle, it was not necessary to prepare the frog according to Galvani's method. On connecting any two parts of its body, as, for example, the head and legs, by means of the galvanometer, he at once obtained a deviation. In 1841, he advanced the following law :—" The interior of a muscle, placed in connection with any part whatever of the same animal, such as nerve, surface of muscle, skin, &c., produces a current which goes in the animal from the muscular part to that which is not so."* In this paper, he first described his *muscular pile*, consisting of about twenty frogs' thighs, roughly cut across, and arranged, as seen in Plate VIII. fig. 35. By connecting the stump of the knee with one wire leading to the galvanometer, and the section of the femur with the other, the needle was at once deflected so as to indicate a current passing upwards in the pile from the knee to the thigh. He considered this to be a current different from the frog current of Nobili, and he held that the frog had two currents, (1.) The muscular current (Nobili's) common to all animals ; and (2.) The special current, evolved by the muscular pile, peculiar to the frog.

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* *Ann. de chim. et de Phys.*, 1828. Nobili.

† Matteucci. Essai sur les phénomènes électriques, &c. 1840. Traité des phénomenes électro-physiologiques des animaux 1844.

In 1841, Professor Emil Du Bois-Reymond, of Berlin, repeated Matteucci's experiments, and further investigated the subject with the aid of the most delicate galvanometers, and other ingenious apparatus, constructed by himself. He at length elucidated the law of *the muscular current* as at present understood. This law may be shortly expressed as follows :— "*Any point of the natural or artificial longitudinal section of the muscle is positive in relation to any point of the natural or artificial transverse section.*"† By "longitudinal section," is meant the surface formed by the side of the muscle, or by the sides of the muscular fibres, when these are separated from each other ; and by "transverse section," is meant a surface formed by the base of the fibres. Both transverse and longitudinal sections may be natural or artificial. This muscular current may be found in the muscles of all animals, and there is, acccording to Du Bois-Reymond, no current peculiar to the frog, as Matteucci supposed. From this period a new impulse was given to experimental physiology by the aid of modern instruments of precision.

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* Matteucci, *Comptes-Rendus*, tom. xiii., p. 540.

† Du Bois-Reymond. Untersuchungen über thierische Elektricität. Berlin. 1848.

Theoretical Explanations of the Muscular Current.—Du Bois-Reymond supposes that a muscular fibre is composed of electrical molecules, which he calls *peripolar molecules*, each molecule having an equatorial belt, manifesting positive electricity, placed between two polar regions occupied by negative electricity. (See Pl. VIII. fig. 36). When a transverse section of muscle is made, the negative poles of the component molecules will be laid bare, and thus the section will shew negative electricity, and as the equatorial belts of positive electricity are directed towards the longitudinal surface, that surface will shew positive electricity. Du Bois-Reymond has, indeed, constructed an apparatus which illustrates his hypothesis of the electro-motor constituents of a muscle. This consists of a number of small cylinders of copper (negative element), having two small strips of zinc (positive element) soldered to their outer surface, facing each other on opposite sides. These are fastened in rows, by their ends, to a board provided with a handle on its upper surface. Such a combination as this, when immersed in a fluid, has produced a current corresponding to the muscular current, going from the longitudinal to the transverse section.

Dr C. B. Radcliffe,* of London, has advanced the hypothesis, that in a muscular fibre two sets of electrical molecules exist, the one set in which positive electricity is external and negative internal, arranged round the outside of the fibre ; the other set of molecules in which the negative electricity is external and positive internal, being placed in the core of the fibre (Pl. VIII. fig. 37). Thus the longitudinal surface will be positive, because it is formed of molecules, the external surfaces of which are positive; and the transverse surface will be negative, because molecules will be laid bare, the external surfaces of which are negative.

Par-electronomy.—This term (*παράνομος*, *contrary to law*), is applied by Du Bois-Reymond, to describe the electrical condition of the layer of muscle next a tendon, or of muscle which has been subjected to great cold. When a muscle so prepared, that instead of making an artificial transverse section, the tendon is employed as a natural transverse section, is introduced into the galvanometer circuit, there is a deflection of the needle so as to indicate either a very weak current in the usual direction from the longitudinal to the transverse section, or a current in the reverse direction. To explain this, Du Bois-Reymond modified his theory of *peripolar* molecules, and conjectures that muscle is made of *dipolar* molecules, with their positive poles in contact, and their negative poles away from each other. Now, if the layer next the tendon consists of one set of such molecules, they must have their positive poles next the tendinous surface.

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* Radcliffe, Lectures on Epilepsy, Pain, Paralysis, &c. 1864.

Electrical state of a muscle during contraction.—When a portion of muscle is properly placed in the galvanometer circuit, there is a deflection of the needle to an extent proportionate to the strength of the current. If, after allowing the needle to come to rest, the muscle be now thrown into a state of contraction by any irritant, such as strychnine, common salt, or an interrupted current, the needle at once returns in the direction of zero, and after oscillating for a few seconds, comes to rest near to but seldom at that point. The muscular current has been diminished. Occasionally the needle will pass to the other or negative side of zero. When this takes place, the phenomenon is termed *negative variation*, and is the result of another counter current produced at the electrodes, and which acts when the ordinary muscular current is weakened or destroyed by contraction.*

When the two hands are introduced into the circuit of the galvanometer in the manner to be described in treating of Practical Physiology, we find no deflection of the needle till the muscles of one of the arms are caused to contract, when there is a slight deflection of the needle indicating an upward current in that arm. On contracting both arms we get irregular deflections. This current, developed during contraction, is the negative variation of the muscular current of the limb. While the muscles of both arms are inactive, their currents being both feebly positive, are in equilibrium, and there is no deflection of the needle; but on the muscles of one arm only being contracted, it becomes negative, and gives rise to a slight deflection of the needle.

Matteucci's secondary contraction.—When two frogs' limbs, prepared according to Galvani's method, one having the sciatic nerve dissected out, are placed near each other on an insulating plate, it will be found that if the nerve of the one limb be laid on the muscles of the other, and a shock is given to the latter, the muscles of the other limb will contract. In like manner, if two nerves, each connected with a limb, are laid on each other, an electrical shock to one limb will at once induce contraction in the other. This secondary contraction is the result of the negative variation of the ordinary muscular current produced.

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* Du Bois-Reymond, *Op. Cit.*

Cutaneous currents.—Du Bois-Reymond* also found on applying a piece of the skin of a frog to the cushions of the galvanometer, that there was a distinct current flowing from the external to the internal surface, which was easily destroyed by the application of irritants, for example, saline solutions.

Nerve current.—Du Bois-Reymond discovered that when a portion of nerve is introduced into the galvanometer circuit, so that the longitudinal surface is in contact with one electrotode, and the transverse with the other, there is a distinct but comparatively slight deflection of the needle indicating a current running from the longitudinal (positive) to the transverse (negative) surfaces.

Effects of electricity on nerves. — An interrupted galvanic current transmitted along a nerve weakens, and if too long continued, destroys the nerve current and the excitability of the nerve. But if a constant galvanic stream be sent along a portion of nerve, it is thrown into a peculiar condition, called by Du Bois-Reymond the *electrotonic state* (ἠλέκτρον, electricity; τόνος, tension. This term was first used by Faraday to describe the peculiar molecular condition of a wire traversed by a current of electricity. If the constant stream passes in the natural direction of the nerve current, this electrotonic state is augmented; if in the contrary direction, it is diminished. While a portion of nerve is in an electrotonic state, it may be shewn experimentally, as will be fully described under the head of Practical Physiology, that its physiological action has undergone certain modifications. For the sake of clearness, we shall subdivide this physiological action of the nerve as follows,—1. its electric power, or power of evolving electricity; 2. its conductibility, or power of conducting the influence of impressions; and, 3. its excitability, that is, the property of nerve in virtue of which it is capable of receiving impressions and generating an influence.

While a portion of nerve is traversed by a constant current, it is divided by a neutral point, situated between the two poles, into two areas. The area in the neighbourhood of the positive pole is termed the anelectrotonic area (ἀνυω, upwards; ἠλεκτρον, electricity; and τόνος, tension) while that in the neighbourhood of the negative pole is termed the cathelectrotonic area (κατὰ, downwards; ἤλεκτρον, electricity; and τονος, tension). The anelectrotonic area extends for some distance outside the positive pole, and the cathelectrotonic area for some distance outside the negative pole. The position of the neutral point, or point of indifference, that is the point where the nerve is neither in a cathelectrotonic, nor in an anelectrotonic state, and the extent of the cathelectrotonic and anelectrotonic areas is determined by the strength of the electrical current transmitted through the nerve. With a current of *medium* strength, the neutral point is exactly midway between the two poles, and the two areas are equal in extent, as will be seen in the following diagram :—

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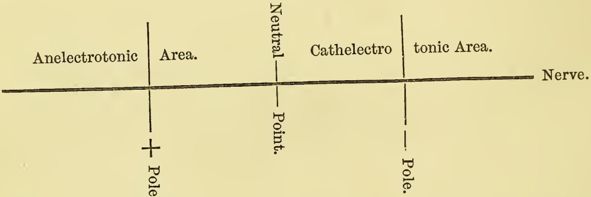
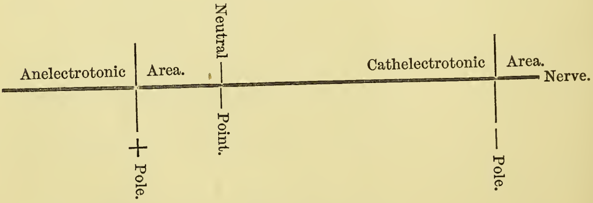
* Du Bois-Reymond, *Op. Cit.*

Medium Current.

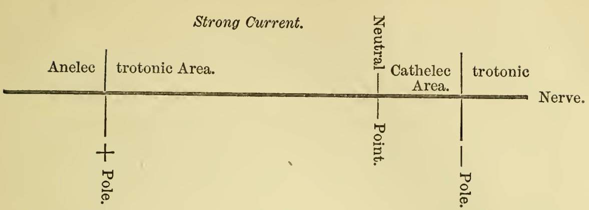

Anelectrotonic
Area.
Neutral
Cathelectro
tonic Area.
Nerve.
+ Pole.
Point.
- Pole.

With a weak current, the neutral point is nearer to the positive than to the negative pole, and the greater portion of the nerve is in a cathelectrotonic condition. Thus :

Weak Current.


Anelectrotonic
Area.
Neutral
Cathelectrotonic
Area.
Nerve.
+ Pole.
Point.
- Pole.

With a strong current, the neutral point is nearer to the negative than to the positive pole, and the greater portion of the nerve is in an anelectrotonic condition. Thus :



Of course intermediate strengths of the current will cause intermediate positions of the neutral point.

Pflüger discovered that under these circumstances the excitability and conductibility of the nerve are diminished in the neighbourhood of the *positive* pole, while its electric power is increased ; but the excitability and conductibility of the nerve are increased in the neighbourhood of the *negative* pole, while its electric power is diminished. In other words, when a portion of nerve is in the anelectrotonic condition, its power of receiving impressions is diminished, it does not conduct nervous force so rapidly, but it evolves more electricity than it would do in the normal state. The reverse is the case when a portion of nerve is in the cathelectrotonic state. It is then more excitable, conducts nervous force more rapidly, but its power of evolving electricity is diminished.

These results may be impressed on the memory by the aid of the following table :—

STATE OF NERVE.	FUNCTION OF NERVE.		
	Electric Power.	Conductibility.	Excitability.
Anelectrotonus	Increased.	Diminished.	Diminished.
Cathelectrotonus	Diminished.	Increased.	Increased.

Pflüger's Law of Contraction.—By the law of contraction is meant all the actions which a muscle exhibits on opening or closing a current, varying in strength and direction, passing through its nerve. Many of the earliest experimenters in electro-physiology were struck by the fact, often observed, that a *feeble* current of electricity acting on a nerve will cause contraction in a muscle when a *strong* current fails to do so. It was also observed that while a constant current was flowing through a portion of nerve attached to a muscle, the muscle contracted *only on opening and closing the current*, and not during the passage of the current. But the muscle sometimes contracted, sometimes it did not. Numerous experiments, made by Du Bois-Reymond, Eckhard, Pfaff, Ritter, Nobili, Pflüger, Schiff, Wundt, Cl. Bernard, Fick, and C. Bland Radcliffe, have shewn that the phenomenon of the contraction of the muscle is influenced, *first*, by the direction, and, *second*, by the strength of the current sent through the nerve. In the description of these phenomena, physiologists have made use of certain terms it is necessary to explain. When the current is transmitted from the muscle in the direction of the spinal cord, the current is called an *upward* and *inward* or *centripetal* current ; when from the cord in the direction of the muscle, it is called a *downward* and *outward* or *centrifugal* current. When the current was derived from only one of Grove's cells, the strength of the current is described as *weak;* when from two or three of Grove's cells, as *medium;* and when from five or six of Grove's cells, as *strong.* In these experiments, small elements or cells are employed, and an instrument, termed a rheocord, for further regulating the strength of the current, is introduced into the circuit. (See Practical Physiology.) By means of an instrument, termed Du Bois-Reymond's key, the current may be opened or closed at pleasure. It is broken or interrupted when the key is *opened,* and is again allowed to pass onwards when the key is *closed.*

The following table shews the results of Pflüger's experiments,* and is sometimes termed *Pflüger's law of contraction,* though it is really a table of facts, to explain which Pflüger has discovered a law called *Pflüger's law of stimulation* :—

Current Strength.	Upward Current.	Downward Current.
Weak . .	*Clos.* Contraction.	*Clos.* Rest.
	Open. Rest.	*Open.* Strong contraction.
Medium . .	*Clos.* Strong contraction.	*Clos.* Strong contraction.
	Open, Strong contraction.	*Open.* Strong contraction.
Strong . .	*Clos.* Rest.	*Clos.* Strong contraction.
	Open. Very strong contraction.	*Clos.* Rest, or feeble contraction.

On beginning with an exceedingly feeble upward current, neither opening nor closing gives rise to contraction ; but, by increasing the strength of the current gradually, we invariably get contraction first on closing, but opening has no effect. By gradually strengthening the current, we at length reach a point when there is contraction both on closing and opening. By and bye, a certain maximum is reached, the closing contraction becomes weaker, and finally disappears when the current becomes strong. Similar results are to be got with a downward current, except that contraction with a weak current first appears, according to many experimenters, on opening and not on closing, and that there is contraction on closing, and none, or a very feeble contraction, on opening a strong current. Pflüger, however, found that with a weak downward current he obtained contraction on closing and rest on opening, a result in accordance with the theory of stimulation he has offered.

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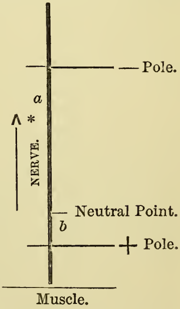
* Pflüger. Electrotonus.

Pflüger's law of stimulation.—To explain these phenomena, Pflüger has propounded the following law :—"*A given piece of nerve is stimulated only by the appearance of cathelectrotonus, and the disappearance of anelectrotonus, but the disappearance of cathelectrotonus and the appearance of anelectrotonus has no effect.*" In other words, when a current is closed, the nerve is stimulated by the passage of the nerve near the negative pole from a normal into a cathelectrotonic state; but when a current is opened, the nerve is stimulated by the passage of the nerve near the positive pole from an anelectrotonic into a normal state.

Pflüger's theory of stimulation affords a satisfactory explanation of the results given in the table already quoted, and it also explains why a feeble current causes contraction more strongly than a powerful one. This will be evident if we apply it to the individual instances by the aid of the following diagrams :—

1*st. Feeble upward current.*—*Closed*, Contraction ; *Opened*, Rest. Here the point of indifference is near the positive pole, and consequently the cathelectrotonic area is extensive. When the current is closed, the nerve is stimulated by the establishment of cathelectrotonus in the portion, *a*, in which the excitability of the nerve is increased, and a contraction of the muscle is the result. On the other hand, on opening the current, a small portion of the nerve in the neighbourhood of the positive pole, *b*, passes from the anelectrotonic into the normal state, and the nerve is stimulated, but the excitability of the



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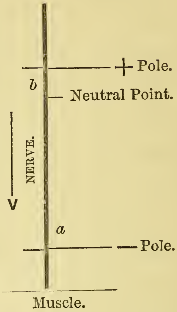
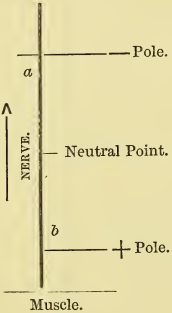
* The arrow ———> indicates the direction of the current.

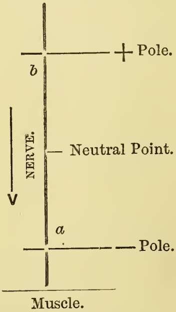
nerve being much lowered, the stimulus is so weak that the muscle does not contract.

2*d. Feeble downward current.—Closed*, Contraction ; *Opened*, Rest (Pflüger). On closing, a large portion of the nerve next the muscle, *a*, passes into the cathelectrotonic state, the nerve is stimulated, and contraction of the muscle is the result ; but, on opening, a small portion of the nerve, at a distance from the muscle, *b*, passes from the anelectrotonic state, and the stimulation is so weak that the muscle does not contract. But, as already mentioned, p. 172, many physiologists have contraction only on opening and none on closing, a result which is not explained by Pflüger's law. The discrepancy probably arises from the great difficulty of graduating the strength of the current



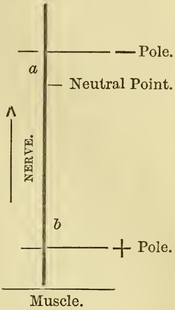
3*d.* and 4*th. Medium upward and downward current.—Closed*, Contraction ; *Opened*, Contraction. In this instance, the neutral point being midway between the two poles, the anelectrotonic and cathelectrotonic areas are equal in extent. On both opening and closing, there is strong contraction, because both anelectrotonus and cathelectrotonus increase with the current strength ; and with the increase in the extent of the anelectrotonic portion, *b*, there is also an opening contraction. On closing, the nerve is stimulated in the neighbourhood of the negative



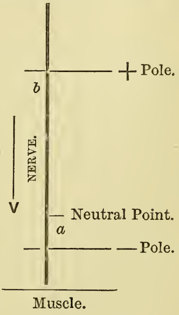


pole, *a*, by the establishment of cathelectrotonus ; and on opening, the nerve is stimulated in the neighbourhood of the positive pole, *b*, by the disappearance of anelectrotonus.

5th. *Strong upward current.—Closed*, Rest ; *Opened*, Contraction. In this instance, the neutral point is near the negative pole, and the cathelectrotonic area is much smaller than the anelectrontonic. On closing, the small portion, *a*, passes into the cathelectrotonic state ; the nerve is stimulated, but as the stimulation has not sufficient power to travel along the anelectrotonic portion, *b*, in which the conductibility is much diminished, there is no contraction of the muscle. On opening, the portion, *b*, passes from the anelectrotonic into the normal state, nerve is stimulated thereby, and the muscle contracts.



6th. *Strong downward current.—Closed*, Contraction ; *Opened*, Rest, or feeble contraction. The closing contraction in this case is caused by the formation of cathelectrotonus in the portion of the nerve, *a*, next to the muscle. But on opening the current, there is usually no contraction of the muscle, or at best a very feeble contraction, because the stimulation arising from the passage of the portion, *b*, from the anelectrotonic to the normal state cannot reach the muscle, owing to the existence in the portion *a* of a peculiar molecular state greatly diminishing its conductibility, termed by Pflüger the *negative modification.*



Another important law, discovered by Pflüger, may be thus expressed, namely,—*The further a nerve is irritated from the muscle, the greater is the excitability of the one, and the contraction of the other.* Two theories have been advanced in explanation. One supposes that the molecules throughout the nerve possess a certain amount of tonic force, a part of which is given off during the transmission of the influence, so that, as the current progresses it receives accumulated intensity, like an avalanche as it rushes down a precipice. The other theory supposes that a motor nerve becomes more excitable the nearer it approaches the nervous centre or its origin, so that an irritant produces a more marked effect when applied there than at a distance.

It must be obvious that the knowledge of the facts now referred to, regarding the varied effects produced in muscles by the strength, direction, and position of the applied current, must be of the greatest importance to the medical man in his endeavours to employ electricity as a therapeutic agent in the treatment of paralysis, neuralgia, and other nervous diseases.

Sensory nerves.—The electrical phenomena of sensory nerves, and the effects of electricity upon them, are the same as those just described relating to motor nerves. Each sensory nerve is excited by electricity in its own special way. Irritation of the optic nerve produces a sensation of light; of the auditory nerve, sound; of the gustatory nerve, taste; of the nasal nerve, smell; and of the ordinary sensory nerves, pain.*

VITAL PROPERTIES OF THE TISSUES.

While the tissues, as we have seen, possess those properties which, as belonging to matter in general, we call physical, they also possess others which, as only occurring in living bodies, are peculiar and distinctive, and which are denominated vital. These are, 1st. Differentiation in growth; 2d. Contractility; 3d. Sensibility; and 4th. Mental acts, including volition and sensation.

1. *Differentiation in Growth.*—At one period in the history of all vital growths, the individual presented the structure of a finely molecular mass, such as the yolk of an egg, the substance of a seed or spore, or a simple mass of protoplasm or proligerous matter. If we examine two ova, or two seeds of the same size and form, this matter appears to be identical, whether analysed by the chemist, investigated structurally by the histologist, or carefully scrutinized by the physicist, yet from one such

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*Regarding electric taste, sight, hearing, smell, and feeling, see Morgan's "Electro-Physiology," p. 619. For other facts relating to Electro-Physiology, see Morgan *Op. Cit.*; Du Bois-Reymond, Thierische Elektricität; Pflüger, Electrotonus; Heidenhain, Physiologische Studien; Von Bezold, and Rosenthal, über Gesetz. d. Zuckungen, *Reichert's Archiv.* 1859, p. 131; Bland Radcliffe, Lectures on Epilepsy, Pain, Paralysis, &c. London. 1864., &c.

egg may come a swan, and from the other, a goose ; and from one such seed may come a lemon, and from the other, an orange tree. Mammalian ova are comparatively minute in size, and out of two which closely resemble one another may be developed a mouse and an elephant.

Again, if we watch the development of an animal, say a bird, as it is formed within the egg shell, we shall find that out of the molecular matter of the yolk, there is gradually produced membranes, blood corpuscles, blood vessels, the muscular and fibrous tissues, cartilage and bone, nerves and brain, feathers, claws, &c., &c. The physical conditions under which these varied results appear, are usually diffused through the entire germinating mass. The variations seen in the tissues of one animal or plant, as well as those constituting the differences between animals and plants generally are, therefore, the results of what we call a differentiating power of growth. Why the molecular mass forming these yolks of ova should so divide, subdivide, develope themselves into cells which should arrange themselves into tissues, organs, and organisms, so as ultimately to form such different animals and textures, we are profoundly ignorant. A crystal or a mass of rock, may in one sense, be said to grow or increase by aggregation of particles, but these particles are alike, and the differences which exist between different crystals and rocks may, at a very early period, be attributed to varied chemical composition, or physical conditions. The latter distinctions cannot be detected in the case of similar ova and seeds to which we have referred, while the result of development is to produce marked differences in parts. We are therefore obliged to consider the cause of this differentiation in growth to be as yet unknown ; to be a peculiar one, hitherto only found in connection with living bodies, and which therefore, we call vital.

2. *Contractility.*—Elasticity is manifested by forcibly compressing, bending, or drawing out a body, which, on the withdrawal of the external force by its power of recoil, returns to its original form. Contractility is the reverse of this process. The substance is shortened, by an inherent drawing together, or aggregation of, its constituent particles, in the first place, with a certain amount of force which brings bodies, to which its ends are attached closer together, and when the contractile power ceases, the substance is relaxed, and then returns to its original

form. This power in the living economy may be applied to various purposes, not only in the case of muscles, to bring the parts they may be attached to in proximity, but to occasion a variety of other movements, as in the iris, to dilate and contract the pupil, to produce a rapidly moving surface, as with cilia, occasion independent motions, as in spermatozoids and vibriones, amœboid movements, &c., &c.

From the fact that contractility may be seen in simple filaments, as in vibriones ; as in the spermatozoid and cilium ; in isolated protoplasm, as well as in the ultimate fibrillæ of muscle (Fig. 46), it must be clear that this property is attached to the minutest molecules of the tissue. That it was independent of the nervous influence, though capable of being excited through the nerves, was first maintained by Haller, and admits of demonstration in many ways. Thus, first, John Reid, after removing the sciatic nerve from the limb of a frog, exhausted the muscular contractility, by continued galvanic shocks, and observed that while contractility returned after a certain time, sensibility did not. Secondly, E. Weber isolated a fasciculus under the microscope, and still found it contractile. Thirdly, Harless proved that, when sensibility was destroyed by means of ether, to such an extent, that muscular contractions could not be produced by galvanic shocks applied to the nervous centres, they occurred immediately similar shocks were applied to the muscles themselves. Fourthly, plants have no nerves, and yet some of their tissues are contractile. Other arguments may be drawn from the influence of irritants, poisons, and of galvanism on muscles. The various kinds of contractile tissue, are not all induced to contract by the same stimuli. Thus, cold will excite action in the fibres surrounding certain bulbs of the hair, and in those of the dartos, while mechanical irritation and galvanism do not. But mechanical irritation, as well as cold, will cause contraction in the middle coats of the arteries and veins, but not galvanism. All three kinds of irritation act on the fibres of the iris, and contractile coats of the hollow viscera, and the capillary vessels in addition to these, are influenced by certain emotions of the mind, but not by volition. The highest degree of contractility exists in voluntary muscle, which, in addition to all the other stimuli, are contracted through the mind at will.

It must be clear from a consideration of all the facts connected with contractility, that this property is utterly unlike that of elasticity, or other physical phenomena possessed by matter generally, that it is only visible in living tissues, and like differentiation in growth, is therefore a proof of vitality.

Sensibility.—By this term is to be understood that remarkable property of nervous matter, in virtue of which, when it is irritated, a something is produced which we call an influence that is conducted in various directions along the nerves. These nerves, although alike in chemical constitution, ultimate structure, and physical attributes, convey the influences of different impressions, some only in one direction, and others only in another. But further than this, some of these nerves can only be excited or stimulated to produce the influence which is conducted, by one kind of irritant, and others by another kind. Thus, all manner of mechanical irritants, such as pricking, burning, rubbing, pressure, &c., will excite the nerves of common sensibility, while the optic and auditory nerves may be excited by light and sound, which produce little effect on the others. Equally different kinds of sensibility exist in other nerves—some responding to one kind of stimulus, and others to another, and as a result, varied actions produced at a distance from the parts where the irritation was applied. Thus if the influence is conducted by the nerves to the brain, various sensations are produced ; if to contractile parts, varied kinds of movements ; if to the glands, varied sensations ; and if to the tissues, varied alterations in growth, &c. A copper wire, like a nerve, is capable of conveying varied physical influences, such as heat, sound, and electricity, but these influences are generated outside the wire, and simply conducted by it. But when a nerve is struck it generates as well as conducts its own peculiar influence. Apply the point of a needle to a wire no effect results—do so to a nerve, and spasm, pain, a noise or a flash of light may occur, according as the nerve conveys the influence produced to the muscles, the brain, the ear, or the eye. Sensibility, therefore, though in some respects analogous, is broadly distinct from all kinds of physical phenomena ; is only to be recognised in living beings, and, as such, must be considered as essentially vital.

Mental acts, including volition and sensation.—By the mind we understand that property of brain whereby we will, we feel, and we think. Many of the inferior animals will, feel, and think like ourselves, although the degree with which they do the last may differ. An elephant adapts means to an end as the result of thought, often with great sagacity, and the same unquestionably exists in other creatures, in whom it is variously modified, and may be observed imperceptibly to pass into automatic or instinctive actions.

The ancient Egyptians, Arabians, Hebrews, Persians, and Greeks, believed that many of the mental faculties and feelings were seated in the thoracic or abdominal viscera. So old and so widely spread was this hypothesis, that it still keeps a hold of the literature and colloquial language of every people. Hence, the heart, the liver, the spleen, the reins, and the bowels, are among all nations referred to, either literally or figuratively, as so many seats of mental faculties or moral feelings. It was Galen who distinctly maintained that the brain was the organ of the mind and centre of sensation and volition, a view which has been universally held by all distinguished physiologists since his time, and may be regarded as thoroughly established by every trustworthy experiment and observation with which mankind is acquainted. With regard to the relation existing between mind and brain, two views are contended for. One, that the brain originates, the other, that it is only the instrument of, thought. According to the first view, the brain thinks as a muscle contracts, in virtue of a peculiar vital property inherent in its ultimate molecules. According to the second view, the brain is played upon by a hypothetical immaterial agent, as a piano is played upon by a musician. The discussion is metaphysical rather than physiological, because the phenomena observed in every case are the same. It has been well said, "that a piano out of tune will yield discordant music, let the performer be ever so skilful, and that a penny whistle can never have the clang of a trumpet." Whether, then, we regard the brain as a producing organ or as an instrument, everything will depend upon the structure and quality of the instrument itself. There is, however, no more difficulty in regarding consciousness as a property of the brain than there is in considering sensibility to be a property of nerve, or elasticity the property of a steel spring. Of the nature of all these properties, whether physical or vital, we are ignorant. But inasmuch as we never recognise mental acts, except in animals who possess brains, any more than we observe sensibility where there are no nerves, or contractility where there is no contractile substance, so physiologists must regard mental manifestations as functions and properties never present in dead matter, but as characteristic of the highest form of animal life, and therefore as vital.

Relation of the physical to the vital forces.—In studying the different phenomena, whether physical or vital, physiologists are in the habit of using the term force much in the same manner that it is used by the general cultivators of science. Mechanics has its forces, such as that of the lever ; chemistry has its forces, like that of affinity ; and physical science has its forces, like that of attraction. Physiology has also its forces. It has been supposed that in the same manner as we have physical attractions and repulsions, so we have vital attractions and repulsions. Then we have germinative, contractile, nervous, and mental forces. The idea of force, whether in physics or physiology, as explanatory of phenomena, must be regarded only as theory, as a mental creation, which we employ as a convenient term to satisfy that intense desire of arriving at definite causes which is instinctive in man. On the other hand, it is often employed to express action, which may be demonstrated and often measured. In this sense it is as applicable to the action of a stomach or of a liver as it is to that of an electric telegraph or a steam-engine.

Correlation of force.—According to Mr Grove, the physical forces are "correlative," or have a relation of mutual dependence, each being capable of producing any one of the rest, either directly or through the medium of some other. Thus, the motion of a body retarded by friction gives rise to heat ; and, conversely, heat applied to any form of matter produces its expansion,—that is, motion. The friction of two dissimilar bodies produces not merely heat, but electricity ; and heat itself, when made to act on certain combinations of metals, also produces electricity ; whilst on the other hand, the electric current may produce heat, light, magnetism, or motion, according to the nature of the substances through which it is transmitted. Light, heat, and electricity, again, are closely related to chemical affinity, which is often specially excited by them, and which can in its turn generate these forces ; a material *substratum* being required in both cases. In the same way, there may be a correlation of the vital forces. Thus, organic molecular matter may produce various tissues having different vital endowments. That converted into muscular tissue, exhibits contractility ; that converted into nerve, excitability. Here also a certain substratum or material substance is requisite for the conversion of one force into another. Then, as we have seen, there is a certain relation between the nervous and muscular forces : one can call the other into action in a degree proportional to its own excitement ; and, again, nervous agency is capable of influencing growth and cell-formation in such a manner as to give rise to the idea that it may be re-converted into the forms of vital force necessary to evolve cells. Again, heat, light, and electricity have long been recognised as excitors or stimuli of the vital forces, and these, operating through a peculiar organised structure, may in fact become vital forces themselves, just as heat becomes electricity when it passes through a certain combination of metals. Thus, vital force may be converted into physical force, and *vice versa*, as when we see some tissues producing chemical action, others mechanical movement, and a third kind, electricity.

Conservation of force.—Whilst any particular force which is the cause of a certain alteration may be exhausted, there is always another force which gains as much power of producing new alterations in nature as the first has lost. It follows, that although it is the nature of all forces to become exhausted by their own working, the power of the whole system in which these alterations take place is neither exhausted nor increased in quantity, but only changed in form. If a watch is wound up, the active force or energy exerted by the muscles of the arm and hand is communicated to the spring, and this again is communicated to the wheels, and is slowly employed in overcoming their friction for twenty-four hours. But if an arrow be discharged from a bow, then the energy employed by the arm is communicated to the arrow and is expended in half a minute in overcoming the pressure of the atmosphere. Heat, light, electricity, gravity, and chemical action are all in like manner capable of being perpetuated in an unceasing round one to the other. And so in the animal body, the vital forces manifested in various ways are in truth only different forms of energy which originate from the chemical changes produced in the digestion of food, in elasticity, in respiration, or in endosmose. Hence, sensibility, and even the exercise of the mind, cannot proceed without nourishment, and we must regard these manifestations of vital force as only a variety of that chemical force generated in nutrition, as this in its turn is only an altered manifestation of some other force.

It has been shewn that when force is apparently exhausted without doing work, it is not lost, but that heat is generated. Thus, when we stir water rapidly in a bowl, and it again comes to rest, it is increased in temperature. If we try to raise a ton weight, we do not succeed, but become very hot, and the same amount of heat is generated as if, practically applied, would create flame, which the savage does when he expends his muscular energy in rubbing together pieces of dry wood, and so lights a fire. In the animal body the heat so occasioned is at once applied to carry on his functions in various ways, and hence the living frame is enabled to convert more force into work than the most perfect steam engine or other mechanical contrivance. When force or energy is dormant, that is, stored up, as in the compressed air of an air-gun, it is called *potential;* but when it is called into action, and is doing work, as when the same gun is discharged, it is called *actual* or *kinetic.*[*]

Origin of force or energy.—The original source of all energy or force in our universe is THE SUN, because it the great source of heat and light. Under the action of the sun's rays, chemical changes occur in plants, and ternary compounds are formed. The *actual* energy of the sun's rays has become the *potential* energy resident in these compounds. This energy is equal to the heat obtained from their combustion. Animals consume plants, and thus acquire chemical tension or power from them. The *potential* energy of the plant products becomes the *actual* or *kinetic* energy of the animal, which enables the heart to pump blood through the body, and the muscles to produce movement and do work. In the animal body, chemical forces are constantly expended in the production of an equivalent amount of mechanical effect, and in the generation of a certain amount of heat. An active working man converts in a day a certain amount of carbon into mechanical effect, and to keep the supply of carbon equal to the demand he must take food. If the work were done at the expense of his muscles alone, Mayer has shewn they would all be oxidised and consumed in mechanical effect in eighty days. The sum of the heat produced by the mechanical work done by the man in a day, and the animal heat generated during the same time, would be exactly equal in amount to the heat caused by the chemical changes that have taken place in the man's body. Thus "all the world's work, with one exception (tidework), is done by the sun, and man himself, prince or peasant, is but a little engine which *directs* merely the energy supplied by the sun." *

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[*] Professor Tait on Thermo-dynamics, p. 51, *et seq.*

But while physical are essential for the manifestation of vital properties, it should never be forgotten that the former are not identical with the latter. On the contrary, vital have peculiarities which broadly distinguish them from physical phenomena, and admit of easy recognition, as we have seen.

LIFE OR VITALITY.

Definition.—Numerous efforts have been made to define life. Without entering upon a criticism of these, it may be said that they are all faulty. Most authors have felt the necessity of pre-supposing some organised structure, the existence of which is taken for granted in their definitions. Bichat says, "Life is the sum total of the functions which resist death;" Treviranus calls it "The constant uniformity of phenomena, with diversity of external influences;" Lawrence says it consists "in the assemblage of all the functions or purposes of organised bodies, and in the general result of their exercise;" Duges calls it "The special activity of organised bodies;" and Béclard, "Organisation in action;" which last gives us, as far as a short phrase can, what is understood by life.

Theory of Life.—It has been supposed that life was an independent principle, capable of being added to or removed from inert matter. Such was the opinion of the ancient philosophers, as allegorically explained by the fable of Prometheus, who animated the marble statue by fire stolen from heaven. In later times, Buffon imagined life, like matter, to be indestructible. According to him, every living molecule had a life of its own, and the method by which it manifested its function depended on its association with other molecules. Thus, the body of an animal or a plant was the aggregation of a multitude of minute living beings arranged in a particular way. The death of the complex compound was simply a dissolution of one of these associations, and the organic molecules thus set at liberty wandered about until they once more combined with a plant or animal—here with a monad, there with a quadruped. The *materia vitæ diffusa* of John Hunter was something similar.

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* Lockyer, "Astronomy," p. 52. 1870.

Our modern view of life is, not that it is independent of matter, but a condition of matter: in other words, that material substances found in the atmosphere, and in plants and animals, influenced by certain forces, have peculiar properties communicated to them. These properties are the power of growth in certain directions, contractility, sensibility, and mental acts; the exercise of any one of which constitutes life. That accidental causes are capable of communicating one or more of these properties to tissues that did not previously possess them, is certain. Thus, exposure to light may influence the movement of the pigment molecules in the skin of the frog and other animals, so that it at once becomes dark or light. The entrance of a spermatozoid into the ovum—that is a vibratile fibre, much like a vibrio, pushing a molecule before it—excites those changes in the yolk which produce an embryo. An unimpregnated uterus is not contractile, but if impregnated, its fibres have, at a certain period, and then only, a vital property communicated to them, and they expel the fœtus. I think no one can doubt that an aggregation of molecules produce a vibrio, which, at first motionless, has contractility communicated to it, and thereby lives. Moreover on following the development of an animal in an egg, it is capable of being seen, that a portion of the original molecular mass is differentiated, and, by histological and chemical changes, is first transformed into muscle, which afterwards becomes contractile; that another mass is transformed into brain and spinal cord, which subsequently possesses sensibility, and lastly, thought. Thus function, in the embryo, is added to organic matter. Growth differentiated produces organs—each of these has its special functions, which, however, are necessary to the others—so that in every organism there is an incessant round, one organ being necessary to the other, and one form of energy or function capable of being converted into or exchanging with another. (See Correlation and Conservation of Force, pp. 181, 182). A seed may exist for thousands of years as a dried organic mass, but if, at the end of that time, it be put into the earth, it will grow, and thereby lives. It was not alive during the whole of that period, but had the capability of living. Such an organic mass may be compared to a clock ready made and wound up, which requires a touch on the pendulum to set it in movement.

It results that the physical and vital forces and properties are intimately united in a living body, and that the activity or life which it exhibits, is the sum of those phenomena which we observe in it. When, therefore, we use the term life, we simply mean that an organised substance is possessed of certain properties partly peculiar or vital, and partly physical, which, when acted upon by appropriate stimuli, are competent to give rise to that series of actions in which life consists. We are as ignorant of the true nature of physical as we are of vital properties. It is from the effects alone that we infer their existence. Hence, if one substance exhibits the property of combustibility, it burns; if another, on being stretched, returns to its original size, it is elastic; and if a third presents differentiated growth, involving assimilation and excretion, or exhibits contractility and sensibility, it lives.

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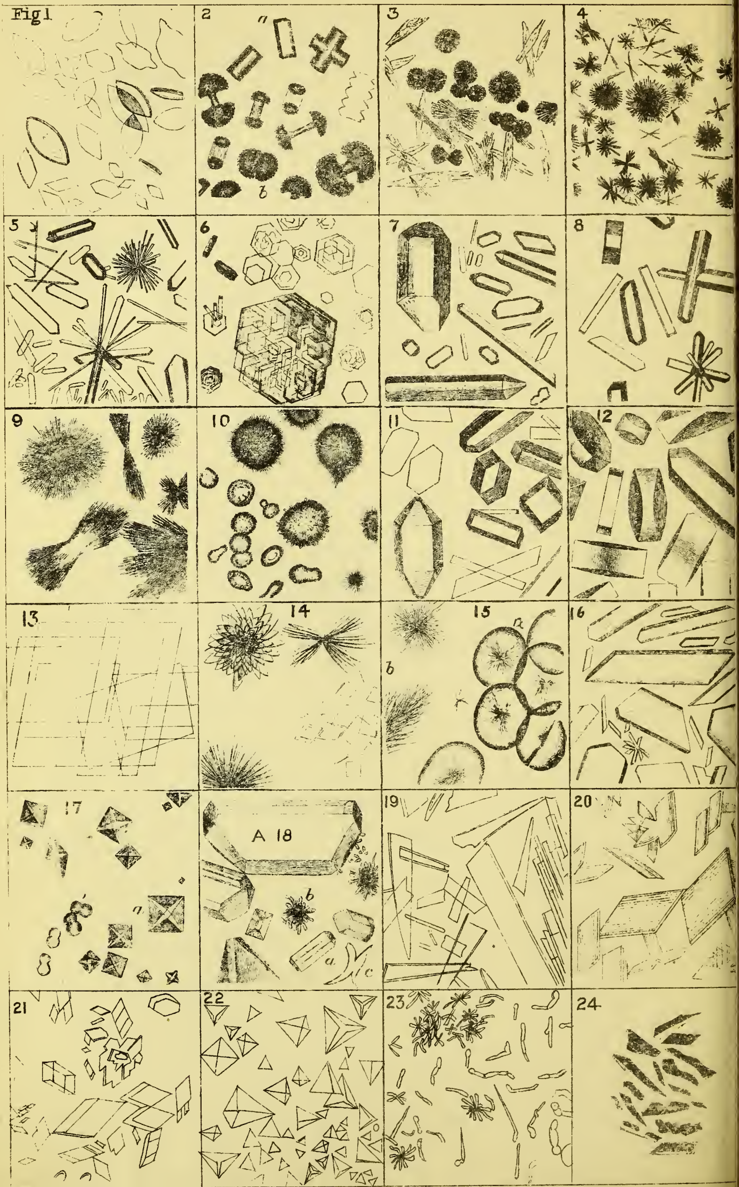
CRYSTALS.

Plate I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Description of Plate I.—Crystals.

Fig. 1. *Uric acid.* Lozenge-shaped crystals with obtuse angles rounded off (pp. 13, 14).

Fig. 2. *Uric acid.* Dumb-bell crystals, and rectangular plates (pp. 13, 14).

Fig. 3. *Urate of Soda.* Acicular crystals forming round masses. Seen in various stages of aggregation (p. 14).

Fig. 4. *Urate of Ammonia.* Acicular crystals forming round masses. Seen in various stages of aggregation (p. 14). See also Fig. 18. *b.*

Fig. 5. *Hippuric acid.* Colourless prisms (p. 15).

Fig. 6. *Cystin.* Six sided plates (p. 16).

Fig. 7. *Taurin.* Six sided prisms terminating in four or six sided pyramids (p. 16.)

Fig. 8. *Allantoin.* Shining colourless prisms (p. 16).

Fig. 9. *Tyrosin.* Stellate groups of long silky needles (p. 17).

Fig. 10. *Leucin.* Balls, composed of scales or needles. Usually of a yellowish colour (p. 17).

Fig. 11. *Creatin.* Clear prisms, with pyramidal ends (p. 18.)

Fig. 12. *Creatinin.* Prisms with rounded ends (p. 18).

Fig. 13. *Cholestrin.* Soft nacreous laminæ (p. 19).

Fig. 14. *Stearin.* Soft nacreous laminæ or needles (p. 20).

Fig. 15. *Margarin.* *a.* Fat cells containing star shaped masses of needles; *b.* Star-like cluster of needles (p. 20).

Fig. 16. *Inosite.* Oblique prisms and tabular plates (p. 27).

Fig. 17. *Oxalate of Lime.* *a.* Octahedral crystals; *b.* Dumb bells (p. 23).

Fig. 18. *Triple phosphate of Ammonia and Magnesia.* A. Large crystal of triple phosphate; *a.* knife-rest crystal of triple phosphate; *b.* amorphous mass of urate of Ammonia; *c.* Clift form of crystal of triple phosphate (p. 29).

Fig. 19. *Hœmatin.* Rectangular plates (p. 32).

Fig. 20. *Hœmatocrystallin* or *Hœmoglobin.* Lozenge shaped crystals, colour dark red (p. 31).

Fig. 21. *Hœmatoidine.* Lozenge shaped thick crystals. This figure shews only the form; they are of a dark red colour (p. 31).

Fig. 22. Triangular blood crystals from a guinea-pig. This figure shews only the form. They are reddish coloured crystals (p. 31).

Fig. 23. Filamentous colouring matter of the bile (p. 32).

Fig. 24. Melanin (p. 31).

MOLECULAR ELEMENTS

Plate II

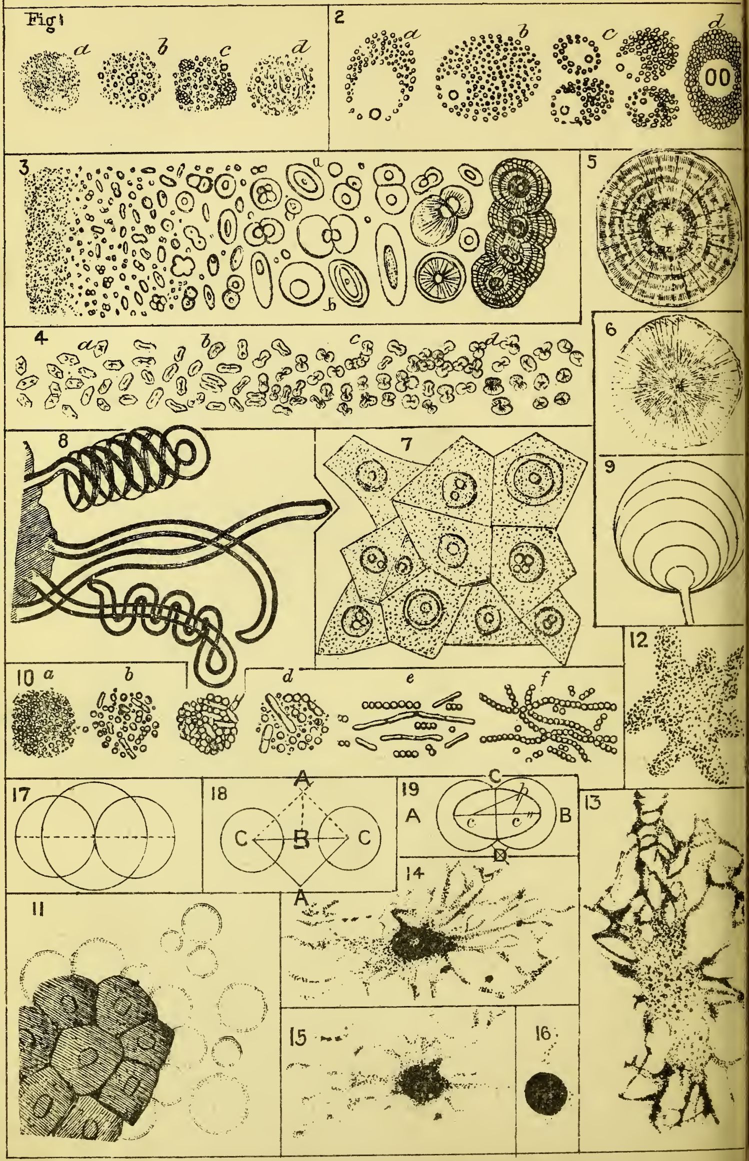
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Plate II.—Molecular Elements of the Tissues.

Fig. 1. *Various arrangements of Molecules.* *a.* Finely molecular mass ; *b.* Molecules varying in size as seen in milk ; *c.* Molecules aggregated in groups ; *d.* Histolytic molecules from broken down fibrous tissue (pp. 36, 37).

Fig. 2. *Fatty Molecules* precipitated from an alcoholic solution, and presenting the various forms here figured, shewing nucleolus, nucleus, and cell-mass, *a*, *b*, *c*,—*d* shews two nuclei (p. 38).

Fig. 3. *Precipitation of Carbonate of Lime,* from a viscous solution on a slide of glass, exhibiting molecular, nuclear, and cell forms in various stages of development. *a.* Oval body containing nucleus ; *b.* round body containing nucleus (p. 37).

Fig. 4. The *crystalline* passing into the *cell form,* the former from a limpid and the latter from a viscous fluid : *a.* crystalline form ; *b.* angles of crystals rounded off ; *c.* ovoid cell forms ; *d.* cell forms aggregated together (p. 37).

Fig. 5. A perfectly formed globular crystal of *Carbonate of Lime,* with radiating lines (p. 42).

Fig. 6. A similar crystal disintegrating (p. 43).

Fig. 7. Flattened crystals of *Carbonate of Lime,* adhering at their edges, from the surface of lime water, resembling epithelium in form (p. 44).

Fig. 8. *Protagon.* Processes shooting out from a mass of protagon on the addition of water, straight, curved, and spiral (p. 45).

Fig. 9. *Protagon.* Occasional concentric layers formed at the extremity of these protagon processes (p. 45).

Fig. 10. *Development of bacteria and vibrios on the surface of an infusion.* *a.* Molecular or proligerous mass ; *b.* larger molecules, with their union together to form short *bacteria* ; *c.* still larger molecules and bacteria ; *d.* the same more separated ; *e.* aggregation of molecules lengthways or melting together of bacteria to form *vibrios* ; *f.* chain-like molecular filaments—*Leptothrix* (pp. 46, 47, 48).

Fig. 11. *Globular diaphanous bodies,* caused by pressing epithelial cells in a viscous dropsical fluid (p. 44).

Fig. 12. An *Amœba,* a contractile molecular mass (p. 47).

Figs. 13, 14, 15, 16. *Vital movements of pigment Molecules.* Effects of diffusion and concentration of molecules in pigment cells in the skin of a frog (pp. 39–40).

Figs. 17, 18, 19. Diagrams explanatory of *Molecular Coalescence* (pp. 41, 42).

CELL ELEMENTS

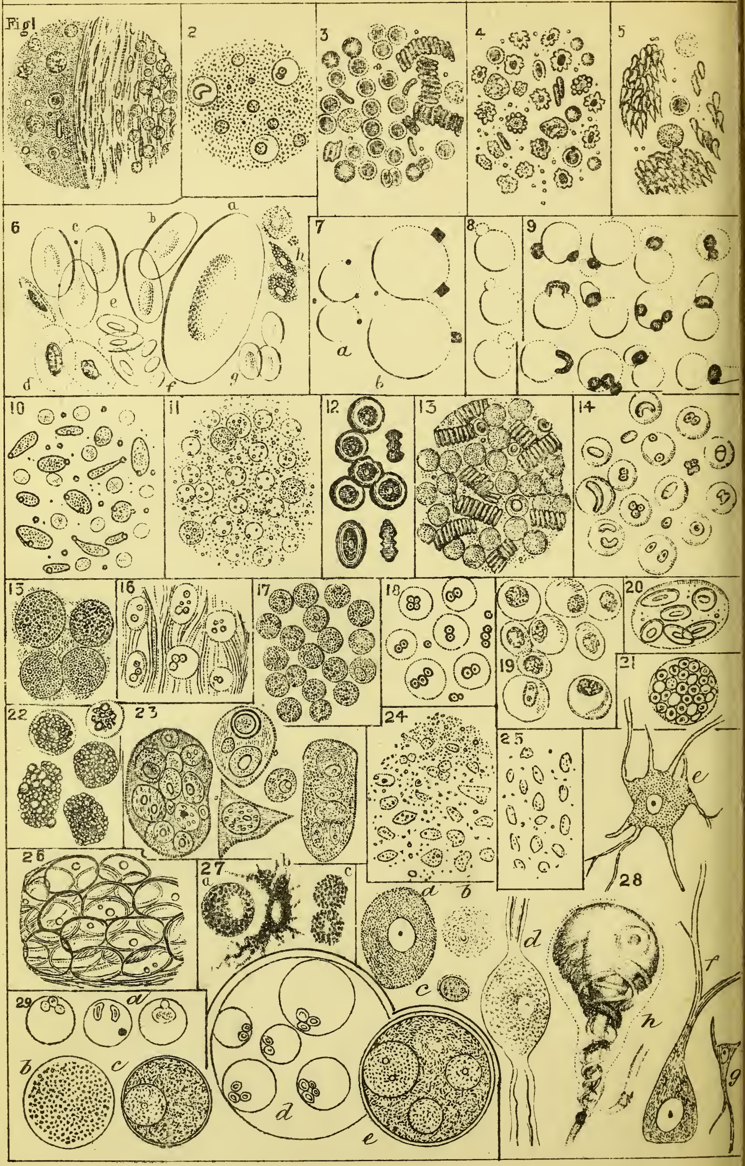
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Plate III.—Cell Elements of the Tissues.

Fig. 1. *Chyle.* A drop of fresh chyle, partly coagulated. On the left of the figure, the corpuscles, some resembling in form coloured corpuscles of blood, the true chyle corpuscles; others those of the colourless, or lymph corpuscles. They float in a finely molecular fluid, the molecular basis of the chyle. On the right of the figure, the fibrillated coagulum, with the corpuscles entangled in it. These are globular in the centre of the coagulum, but flattened and fusiform-shaped towards the margin (p. 60).

Fig. 2. *Chyle.* Effect of acetic acid on the fluid chyle; chyle corpuscles rendered smaller and more opaque with thickened margins. The *lymph corpuscles* more transparent, with distinct nuclei (p. 60).

Fig. 3. *Blood.* Fresh human blood corpuscles. On the left of the figure, isolated; on the right, aggregated in the form of *rouleaux* (p. 61).

Fig. 4. *Blood.* Altered forms of human blood corpuscles, caused by slight evaporation of the fluid, or from adding dense and viscous solutions (p. 63).

Fig. 5. *Blood.* Altered form and mode of aggregation of blood corpuscles when the blood is loaded with fibrin. See also Plate IV. fig. 2 (p. 63).

Fig. 6. *Blood.* Blood corpuscles from different animals. *a.* From proteus; *b.* salamander; *c.* frog; *d.* the same after the addition of acetic acid; *e.* bird; *f.* camelidae; *g.* fish; and, *h.* crab (p. 61).

Fig. 7. *Blood.* Appearance of human blood after the addition of magenta (chloride of Rosaniline). *a.* (600 diameters); *b.* the same (2000 diameters), shewing that the dark molecules on the circumference are crystals (p. 63).

Fig. 8. *Blood.* Human blood corpuscles, after addition of solution of tannic acid (p. 63).

Fig. 9. The same, followed by addition of tincture of iodine (600 diameters) (p. 63).

Fig. 10. *Blood.* Human blood corpuscles from a case of cholera (p. 63).

Fig. 11. *Blood.* Human blood corpuscles disintegrating, from the fluid of a hæmatocele (p. 63).

Fig. 12. *Blood.* Blood corpuscles seen by direct light. The upper group are human, and the lower those of the frog (p. 61).

Fig. 13. *Blood.* Blood corpuscles in leucocythæmia (p. 64).

Fig. 14. The same after the addition of acetic acid (p. 64).

Fig. 15. *Mucus.* Mucous corpuscles, from the fauces.

Fig. 16. *Mucus.* The same after the addition of acetic acid, shewing the molecular fibres of mucin. See also Plate IV. fig. 1.

Fig. 17. *Pus corpuscles* (p. 69).

Fig. 18. The same after the addition of acetic acid (p. 69).

Fig. 19. *Pus corpuscles.* From the fresh fluid of an abscess, surrounded by a hyaline membrane (p. 69).

Fig. 20. *Blood.* Group of birds' blood corpuscles from the brain, surrounded by a hyaline membrane (p. 69).

Fig. 21. *Blood.* Group of human blood corpuscles from an apoplectic clot, surrounded by a hyaline membrane (p. 64).

Fig. 22. *Granule cells* in masses from softened brain (p. 71).

Fig. 23. *Cancer.* Different forms of cancer cells (p. 71).

Fig. 24. *Tubercle corpuscles* from the lung (p. 72).

Fig. 25. The same after the addition of acetic acid (p. 72).

Fig. 26. *Fat cells* (p. 66).

Fig. 27. *Pigment cells. a.* From human lung; *b.* from the skin of frog; *c.* from choroid membrane (p. 67).

Fig. 28. *Nerve cells,* varying greatly in form. *a.* Oval, from gasserian ganglion; *b.* globular, from the same; *c.* oval, or round, from cerebellum; *d.* bi-polar, from ganglion of posterior root of spinal nerve; *e.* multi-polar, from spinal cord; *f.* branched on one side, from grey matter of cerebellum; *g.* triangular, from grey matter of cerebrum; *h.* from sympathetic ganglion of frog, with spiral process, as figured by *Beale* (p. 65).

Fig. 29. *Artificial cells.* Made by mixing protagon with fluids of different densities. *a.* Resembling pus cells; *b.* finely granular cell, with molecular Brunonian movements; *c.* nucleated cell; *d.* cells resembling those of pus surrounded by a hyaline membrane: *e.* compound nucleated cell (p. 45).

Plate IV

FIBROUS ELEMENTS

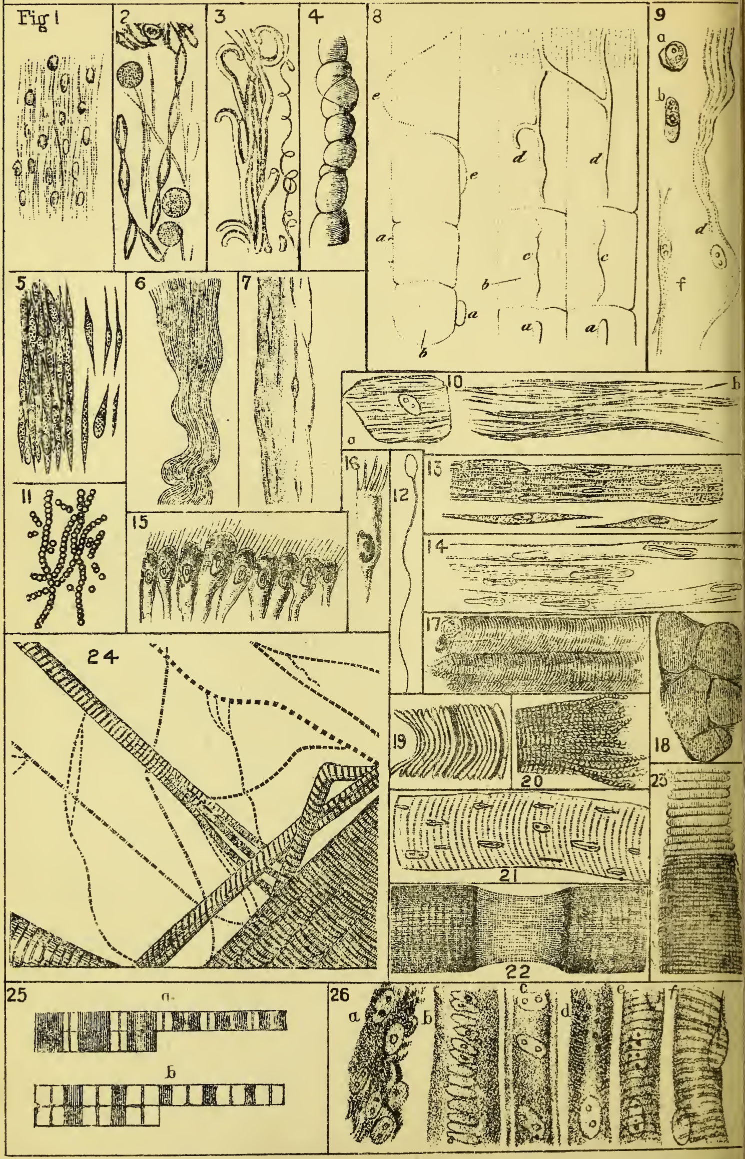
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Plate IV.—Fibrous Elements of the Tissues.

Fig. 1. *Molecular fibres,* with interspersed nuclei in mucin (p. 73).

Fig. 2. *Molecular fibres* in blood loaded with fibrin (p. 73).

Fig. 3. *Nuclear,* or *elastic yellow fibres* (p. 76).

Fig. 4. *Spiral elastic fibres* winding round a bundle of white areolar tissue from the base of the brain (p. 76).

Fig. 5. *Cell fibres* formed by aggregation of fusiform cells (p. 76).

Fig. 6. *White areolar fibres* formed by splitting up of fibre cells (p. 77).

Fig. 7. Bundle of the same after the addition of acetic acid (p. 77).

Fig. 8. Diagrammatic view of the development of *nuclear,* or *elastic tissue. a.* Nucleus ; *b.* cell ; *c.* nucleus elongating ; *d.* elongated and branched nuclei in neighbouring cells uniting ; *e e.* nuclei in neighbouring cells, so uniting as to form the spiral (p. 76).

Fig. 9. Development of *white areolar tissue. a.* fibre cell ; *b.* Fibre cell enlarging lengthways ; *f.* still further elongated, a so-called fusiform cell splitting at both ends ; *d.* a fibre cell splitting up at one end, and forming white areolar tissue (p. 76).

Fig. 10. *Histolytic fibres—a.* epidermic cell splitting up with its nucleus ; *b.* epi dermic cell transformed into fibres, nucleus having disappeared (p. 78).

Fig. 11. *Molecular contractile fibres,* from a recent infusion (p. 73).

Fig. 12. *Nuclear contractile fibre,* with a rounded molecular head, as in Spermatozöid (p. 76).

Fig. 13. *Contractile cell-fibre,* as in non-voluntary muscle (p. 77).

Fig. 14. The same after the addition of acetic acid (p. 77).

Fig. 15. *Contractile fibres* growing from epithelial cells—*Cilia* (p. 77).

Fig. 16. A ciliated epithelial cell more highly magnified (p. 77).

Fig. 17. *Voluntary muscle.* Voluntary muscular fasciculi, with transverse striæ (p. 73).

Fig. 18. Transverse section of voluntary muscle, shewing polygonal form of fasciculi (p. 73).

Fig. 19. Voluntary muscular fasciculus splitting up transversely (p. 73).

Fig. 20. Voluntary muscular fasciculus splitting up longitudinally (p. 73).

Fig. 21. Voluntary muscular fasciculus after addition of acetic acid (p. 74).

Fig. 22. Voluntary muscular fasciculus ruptured, shewing sarcolemma (p. 73).

Fig. 23. Living voluntary muscular fasciculus after addition of acetic acid, shewing mode of contraction, with sarcolemma at the margin (p. 73).

Fig. 24. Structure of voluntary muscular fibrillæ (p. 74).

Fig. 25. Ultimate fibrillæ magnified 1200 diameters, shewing alternating light and dark spaces, *a* and *b*, in different foci (p. 74).

Fig. 26. *Development of muscular fibre in the embyro. a.* Nuclei embedded in a molecular blastema ; *b.* nuclei arranged in rows, with the external blastema differentiated ; *c.* the nuclei separated, with further differentiated molecular blastema ; *d.* the transverse striæ appearing in the molecular blastema outside and between the nuclei ; *e.* transverse striæ fully crossing the fasciculus ; *f.* the fasciculus perfectly formed (p. 75).

TUBULAR ELEMENTS

Plate V

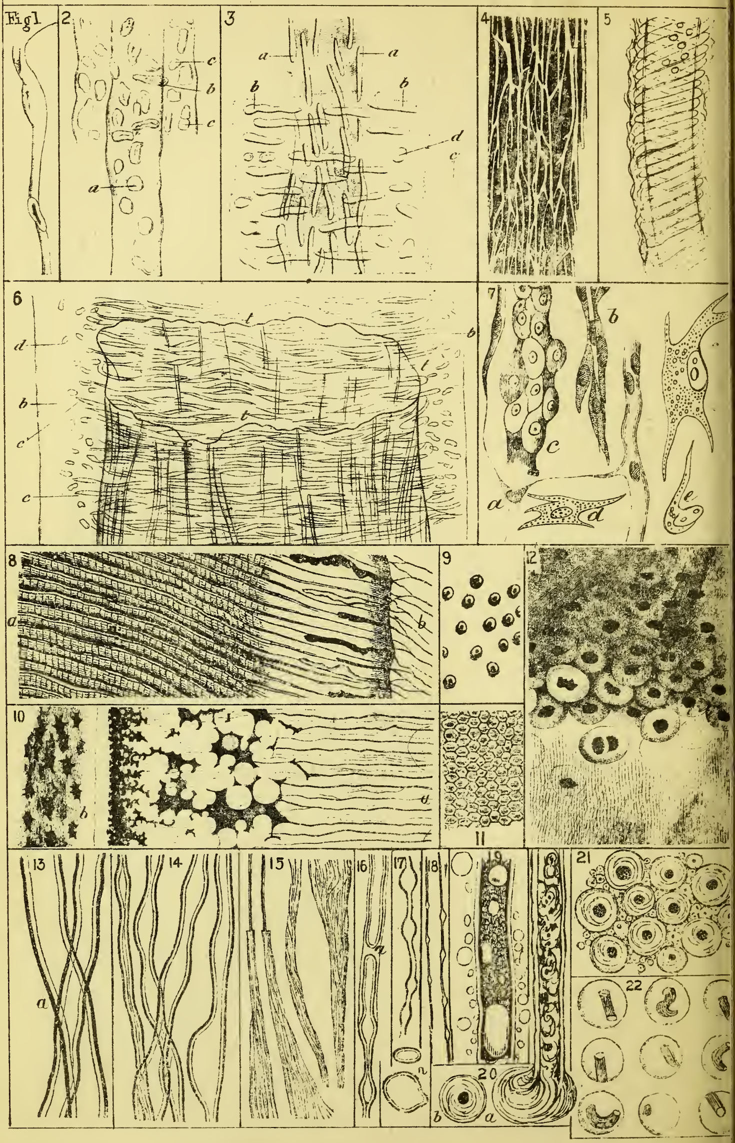
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Plate V.—Tubular Elements of the Tissues.

Fig. 1. *Blood-vessels.* Structure of one of the minutest blood tubes or capillaries. Nuclei irregularly scattered (p. 84).

Fig. 2. *Blood-vessels.* Structure of a small blood tube. *a.* Second or fenestrated membrane; *b.* nuclei arranged transversely; *c.* rounded nuclei (p. 84).

Fig. 3. *Blood-vessels.* Third and fourth muscular layer in a still larger vessel. *a.* Third membrane with longitudinal nuclei; *b.* fourth membrane with transverse nuclei; *c.* external areolar or sixth layer; *d.* transverse section of a nucleus—(p. 84).

Fig. 4. *Blood-vessels.* Elastic coat or fifth membrane of a blood-vessel (p. 84).

Fig. 5. *Blood-vessel.* Spiral arrangement of fusiform cells round a blood tube.—(p. 85.)

Fig. 6. *Blood-vessels.* Third and fourth muscular layer in a vessel twice the diameter of the former one. (Fig. 3) *t, t, t,* Third membrane with longitudinal nuclei, its superior border; *b.* fourth membrane; *c.* its transverse nuclei; *d.* transverse section of one of these (p. 84).

Fig. 7. *Development of blood-vessels.* *a.* Triangular cell uniting itself with the recently formed capillaries; *b.* fusiform cells aggregating together to form a vessel; *c.* layers of cells forming the coats of a blood-vessel; *d.* cell branching to form a vessel; *e* and *f.* similar branching cells in recent exudation (pp. 85, 86).

Fig. 8. *Tooth.* Longitudinal section of enamel. *a.* Enamel; *b.* dentine (p. 87).

Fig. 9. *Tooth.* Transverse section of dental tubes (p. 86).

Fig. 10. *Tooth.* Longitudinal section of dentine and crusta petrosa of tooth. Interglobular substance at the junction of crusta petrosa and dentine. *a.* dentine; *b.* crusta petrosa (pp. 86, 87).

Fig. 11. *Tooth.* Transverse section of enamel (p. 87).

Fig. 12. Transverse section of the grinder of a horse at the junction of crusta petrosa and enamel. The bone cells with their nuclei are seen melting into the crusta petrosa, the latter forming the lacunæ (p. 87).

Fig. 13. Structure of the *nerve tubes* in the senso-motory nerves throughout the body generally, composed 1st, of the *neurilemma* of the nerve tube externally; 2dly, the *white substance of Schwanna;* and, 3dly, in the centre, a viscous fluid which, when coagulated, constitutes the *central axis* (pp. 94, 95).

Fig. 14. *Nerve tubes* from the spinal cord. These are of the same structure, but possess varicosities, and vary greatly in size (p. 95).

Fig. 15. *Nerve tubes* from the spinal cord acted on by water. The white substance of Schwann is coagulated and fibrillated, and the central fluid is now solid, and often projects beyond the lacerated white substanee of Schwann (p. 95).

Figs. 16, 17, 18. Similar but smaller *nerve tubes* from the medulla oblongata and brain. Fig. 16. *a.* The neurilemma of the nerve tube is distinctly seen. Fig. 17. Varicose nerve tubes. Fig. 18 are the finest nerve tubes towards the circumference of the cerebrum. Fig. 17. *a,* Globules varying in size and shape, formed of the white substance of Schwann squeezed out of the tube (pp. 95, 96).

Fig. 19. *Nerve tube* after addition of sulphuric ether, shewing loose globules of oil inside, and of ether outside.

Fig. 20. A *nerve tube,* at one end of which, *a,* the central fluid has been squeezed out, forming a coagulated mass with concentric circles. *b.* Transverse section of a nerve tube after steeping in chromic acid and a solution of carmine. There is seen the transverse section of the central rod or axis, surrounded by the concentric laminæ of the white substance of Schwann (pp. 95, 96).

Fig. 21. Transverse section of *white substance of spinal cord,* shewing nerve tubes greatly varying in size, and each exhibiting the dark central axis of the nerve tube highly coloured, surrounded by the fibrillated white substance of Schwann (p. 95).

Fig. 22. Transverse section of *nerve tubes,* shewing portions of the tinted central axis dragged out by a blunt knife.

CARTILAGE AND BONE

Plate VI

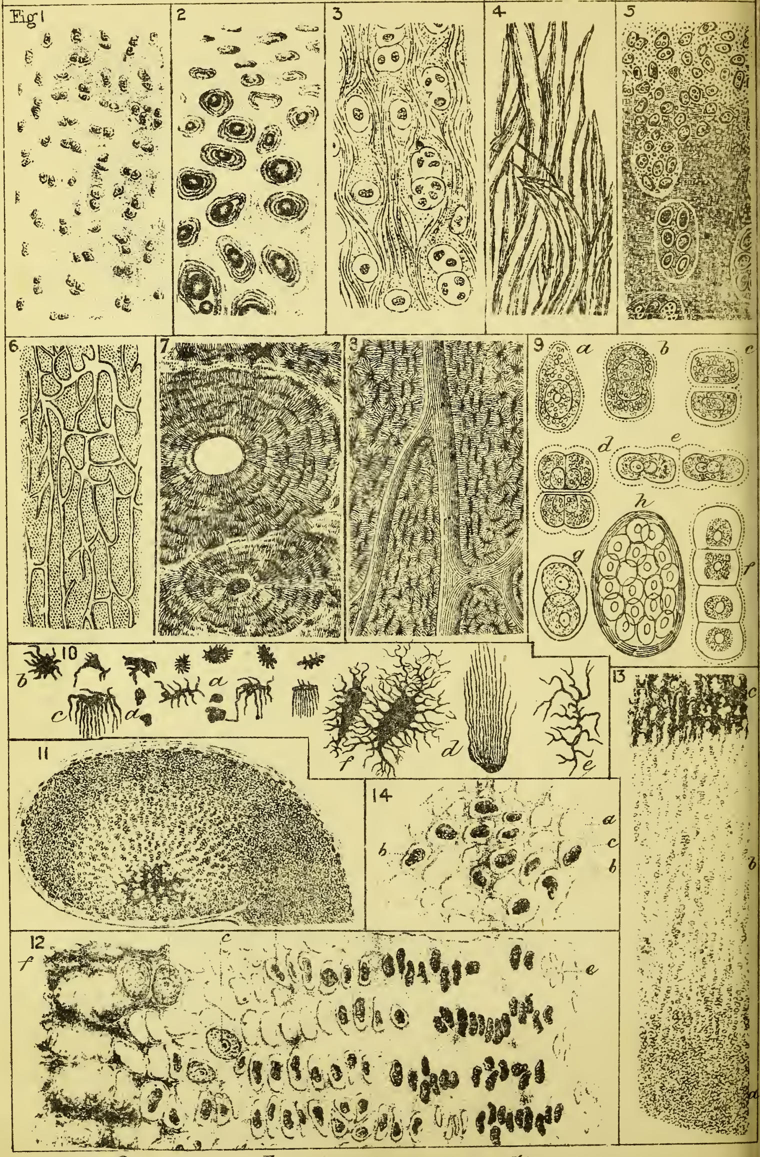
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Plate VI.—Structure of Cartilage and Bone.

Fig. 1. *Cartilage.* Section through the articular surface of a metatarsal bone, 100 diameters linear (p. 88).

Fig. 2. *Cartilage.* Section of a cartilage of a rabbit's ear. 250 d. (p. 89).

Fig. 3. *Fibro-cartilage.* 250 d. (p. 89).

Fig. 4. *Diseased cartilage.*—Fibrous degeneration of cartilage from diseased joint. 250 d. (p. 89).

Fig. 5. *Diseased cartilage.* Endogenous multiplication and bursting of cells in pulpy degeneration of articular cartilage. 250 d. (p. 89).

Fig. 6. *Bone.* Vertical section of a long bone, shewing Haversian canals, and their anastomoses. 20 d. (p. 90).

Fig 7. *Bone.* Tranverse section of a long bone. 250 d. (p. 90).

Fig. 8. *Bone.* Vertical section of a long bone. 250 d. (p. 90).

Fig. 9. *Cartilage cells.* *a, b, c, d, e, f.* Fissiparous multiplication in articular surface of a long bone (p. 88); *g h.* Endogenous multiplication from a velvety or diseased cartilage of the femur. 400 d. (p. 89)

Fig. 10. *Various forms of lacunæ and canaliculi in bone.* *a a.* Simple irregular cavities from an ossification of the pleura ; *b.* from human bone ; *c.* a lacuna next the Haversian canal, with most of its canaliculi towards the canal ; *d.* lacunæ and canaliculi from the boa, also next the Haversian canal ; *e.* canaliculi without a lacuna. 250 d. ; *f.* lacunæ and canaliculi shewing their mode of anastomosis. 500 d. (p. 91).

Fig. 11. *Ossification.* Transverse section through a portion of fœtal vertebral bone shewing commencement of ossification. 40 d. (pp. 93, 94).

Fig. 12. *Ossification.* Vertical section through the epiphysis of the tibia of a new-born kitten. *a.* Cartilage cells arranged in rows ; *b.* cartilage cells shrunk within their cavities ; *c.* cartilage cells still filling the cavities ; *d. e.* cartilage cells on the surface ; *f.* calcareous ridges between rows of cartilage cells, forming cancelli and Haversian canals. 250 d. (pp. 93, 94).

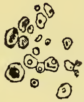
Fig. 13. *Ossification.* Vertical section through a fœtal long bone shewing commencement of ossification. *a.* cartilage ; *b.* cartilage cells arranged in rows ; *c.* mineral matter deposited between them. 40 d. (pp. 93, 94).

Fig. 14. *Ossification.* Transverse section through ossifying cartilage of a calf. *a.* Empty cartilage spaces ; *b.* shrunken cartilage cells breaking down ; *c.* transverse section of calcareous ridges. 250 d. (p. 93, 94).

MOLECULAR THEORY

Plate VII

Fig 1



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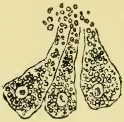

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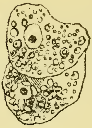

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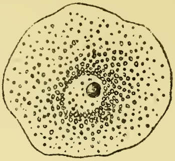

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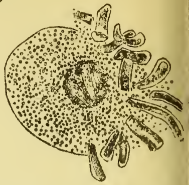

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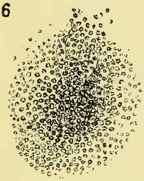

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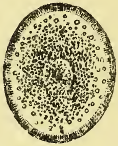

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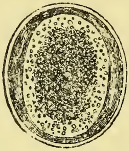

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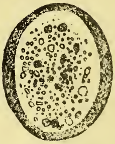

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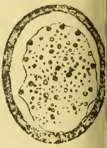

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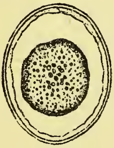

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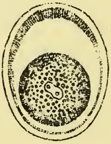

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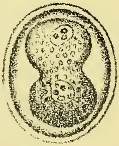

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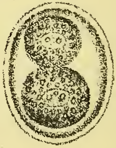

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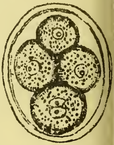

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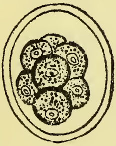

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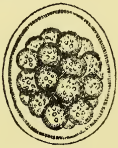

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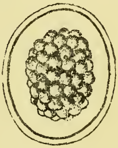

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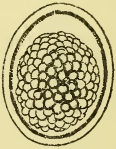

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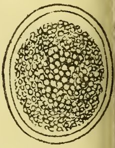

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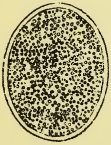

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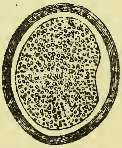

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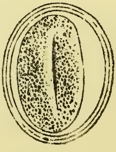

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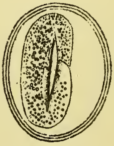

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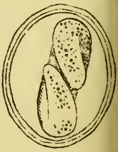

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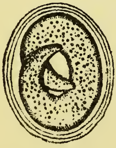

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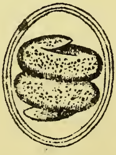

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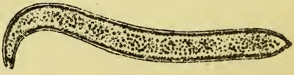

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Plate VII.—Molecular Theory of Organisation, as Illustrated by Development of Ascaris Mystax, after Nelson.

[*See Philosophical Transactions of London*, vol. 142, 1852 (pp. 48–49, *et seq.*)].

Figs. 1 to 4 Represent the histogenetic changes which take place among the molecules deposited in the ovarian tube of the female worm, until the fully maturated ovum (Fig. 4) passes into the oviduct.

Fig. 5. Contact with, and entrance of, the spermatozoids into the ovum. This, the act of impregnation, is followed by gradual solution of the spermatozoids, while the germinal vesicle is still visible.

Fig. 6. This also soon dissolves, and the interior of the ovum is now reduced to a mass of histolytic molecules. Some spermatozoids still undissolved.

Fig. 7. Formation of a chorion externally—spermatozoids dissolved—germinal vesicle still visible.

Fig. 8. Both spermatozoids and germinal vesicle fully dissolved. The histolytic molecules dense in the centre, but beginning to clear up at the circumference.

Figs. 9, 10 shew these molecules clearing up still further, when they meet together, concentrate themselves, and form histogenetic molecules.

Figs. 10, 11 shew this process completed, and a membrane forming round them, another included cell is developed, as in Figs. 11 and 12.

Fig. 12 shews the nucleus beginning to divide.

Fig. 13. The cell now dividing into two.

Fig. 14. The division complete.

Fig. 15. Each half separated into other two.

Figs. 16, 17, 18, 19, 20. The process of division is seen going on in these figures, until another histolytic mass of molecules is produced in Fig. 20.

Fig. 21. This mass begins to clear up by coalescence of the molecules, which again become histogenetic.

Fig. 22. They have now united together, and concentrated themselves, and begin to separate from the vitelline membrane.

Fig. 23. A cup-shaped depression now appears, which, passing through the mass, forms a ring.

Fig. 24. This ring is now seen to be divided at one place.

Fig. 25. The two ends of the ring now elongate, and cross one another, and the molecules go on coalescing, to form the body of the worm.

Figs. 26, 27. The worm now becomes spiral, and, on the bursting of the vitelline wall,

Fig. 28. The perfect animal is extruded.

PHYSICAL PROPERTIES, Plate VIII

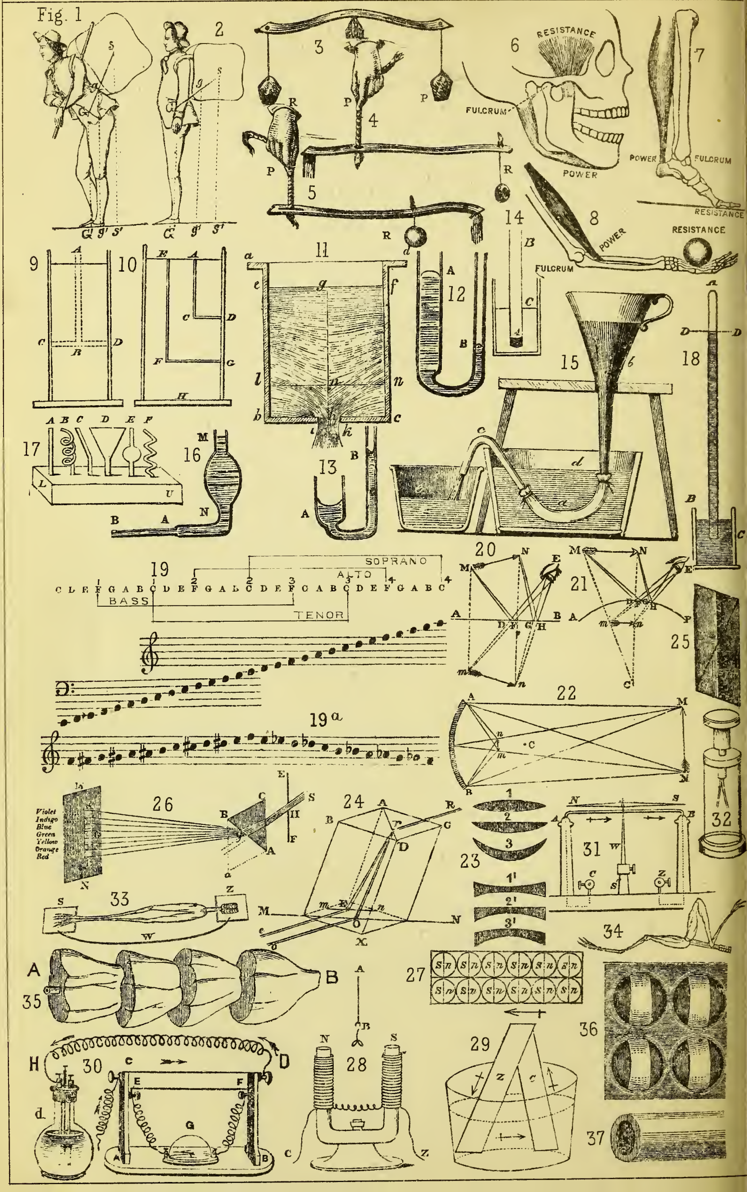
Fig. 1
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RESISTANCE
FULCRUM
POWER
R
P
G g' S'
A B C D
E F G H
a e g f l n b c i k
A B C D E F
L U
M N B A
SOPRANO
ALTO
BASS
TENOR
C D E F G A B C D E F G A B C D E F G A B C D E F G A B C
Violet
Indigo
Blue
Green
Yellow
Orange
Red
M N m n
S Z W
sn sn sn sn sn sn
N S
H C D E F G d
A B

Plate VIII.—Physical Properties of the Tissues.

Figs. 1, 2. Diagram shewing the centre of gravity in a man with and without a burden on his back (p. 107).

Fig. 3. Diagram of a lever of the 1st order ; R, resistance ; P, power ; Fulcrum in the centre (p. 112).

Fig. 4. Diagram of a lever of the 3d order : P, power ; R, resistance (p. 112).

Fig. 5. Diagram of a lever of the 2d order ; P, power ; R, resistance (p. 112).

Fig. 6. An example of the 2d order of lever in the body, as seen in movements of lower jaw in opening the mouth. Resistance is temporal muscle ; Fulcrum is the glenoid cavity in temporal bone ; Power is anterior belly of the digastric (p. 112).

Fig. 7. An example of the 1st order of lever as seen in the act of walking. Resistance is the ground ; Fulcrum is the upper surface of the astragalus ; and Power is the tendo-achilles (p. 112).

Fig. 8. An example of the 3d order of lever, as seen in flexion at the elbow joint. Resistance is the hand, with or without a weight ; Fulcrum is the trochlear surface of the humerus ; and Power is the biceps inserted into tubercle of radius (p. 113).

Fig. 9. Diagram illustrating Pascal's law of the equality of fluid pressure (p. 114).

Fig. 10. Diagram shewing that the pressure of a fluid on any portion of the inner surface of a containing vessel is in proportion to its depth beneath the surface (p. 114).

Fig. 11. Diagram illustrating Torricelli's law that the velocity of the efflux of a fluid is determined by the degree of pressure (p. 119).

Fig. 12. *Capillarity.* Bent glass tube containing *mercury* in equilibrium in the two limbs, shewing that the upper surfaces of the liquid are convex, the tube not being wetted by the mercury (p. 116).

Fig. 13. A similar tube containing *water*, the upper surfaces of the fluid concave, the tube being wetted by the water (p. 116).

Fig. 14. An endosmometer ; B, tube having a membrane, A, tied over one end, and immersed in vessel C (p. 116).

Fig. 15. Apparatus to illustrate the phenomena of diffusion through a blood-vessel along which fluid is flowing (p. 118).

Fig. 16. Poisseulle's tube for experiments upon the discharge of fluids through fine tubes (p 119).

Fig. 17. Arrangement of variously formed tubes, A, B, C, D, E, and F, all communicating with the reservoir L U, to shew hydrostatic equilibrium (p. 115).

Fig. 18. A barometer. A, tube ; B C, cistern containing mercury ; D D, level of mercury in tube (p. 121).

Fig. 19. Diagram shewing the ranges of the different varieties of the human voice (p.133).

Fig. 19^a A chromatic scale formed of semitones, shewing the sharps and flats of the natural notes (p. 133).

Fig. 20. Diagram shewing reflection from a plane mirror. A B, plane of mirror ; E, eye of observer ; M N, object from which the pencils of rays, M D, M F, N G, H, proceed ; N M N, the object as seen in the mirror (p. 135).

Fig. 21. Diagram shewing reflection from a convex mirror. A B, The surface of the mirror ; E, eye of observer ; M N, object ; *m n*, object as seen *behind* the mirror reduced in size (p. 135).

Fig. 22. Diagram shewing reflection from a concave mirror. A B, Surface of the mirror ; M N, object ; *m n*, reflected image reduced in size, inverted, and *before* the mirror (p. 135).

Fig. 23. Various forms of lenses : 1. double convex ; 2. plano-convex ; 3. concavo-convex ; 1^1. double concave ; 2^1. plano-concave ; 3^1. concavo-concave (p. 137).

Fig. 24. Crystal of Iceland spar shewing double refraction. See description (p. 142).

Fig. 25. Nichol's prism for throwing out one of the rays of polarised light (p. 142).

Fig. 26. Arrangement to shew the refrangibility of light. E F, Shutter ; H, aperture in the same ; A B C, prism of glass ; S, ray of light which, instead of proceeding in the direction of the dotted lines, is refracted so as to form the spectrum, M N, shewing the prismatic colours (p. 138).

Fig. 27. Diagram shewing that a magnet may be regarded as composed of hypothetical molecules having southern and northern polarities (p. 145).

Fig. 28. Arrangement to illustrate diamagnetism (p. 146).

Fig. 29. Arrangement to shew the production of a current of voltaic electricity arising from the action of a fluid on one of two heterogeneous metals. Z, zinc plate ; C, copper plate. Arrows shew direction of the current (p. 150).

Fig. 30. Arrangement to shew the production of an induced or Faradic current of electricity. *d.* A bichromate of potash battery (p. 155).

Fig. 31. Arrangement to shew the influence of an electric current on the magnetic needle, N S (p. 148).

Fig. 32. A gold leaf electroscope (p. 148).

Fig. 33. Galvani's experiment (p. 162).

Fig. 34. Experiment of Galvani, Aldini, and Humboldt, shewing contractions in a prepared frog's leg, without the agency of metals or a metallic arc, simply by bringing the leg in contact with the lumbar nerves (p. 164).

Fig. 35. Matteucci's pile of frogs' legs for the production of a current of electricity. A, Femur divided ; B, knee-joint (p. 166).

Fig. 36. Diagrammatic view of Du-Bois Reymond's hypothetical peripolar electrical molecules of which he believes muscular fibre is composed (p. 167).

Fig. 37. Diagrammatic view of Dr Radcliffe's hypothetical electrical cylinders composing muscular fibre, shewing a central nucleus or rod manifesting negative electricity surrounded by a positively electrified covering (p. 167).

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